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Brooks, Wayne Bradford

EFFECT OF TREADMILL RUNNING EXERCISE AT 25 PERCENT AND 75
PERCENT OF MAXIMAL OXYGEN CONSUMPTION ON POST-EXERCISE
RESTING METABOLIC RATE

The Ohio State University

PH.D. 1984

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EFFECT OF TREADMILL RUNNING EXERCISE AT 25% and 75% OF
MAXIMAL OXYGEN CONSUMPTION ON POST-EXERCISE RESTING
METABOLIC RATE

DISSERTATION

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

By

Wayne Bradford Brooks, B.S.Ed., M.Ed.

* * * * *

The Ohio State University

1984

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This work is dedicated to Sue, Julie and Lindsey.

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The Effects of Interval and Continuous Training on VO2Max and Performance in the Mile Run. Journal of Sports Medicine and Physical Fitness, 18:4, 345-352, October-December, 1978.

FIELD OF STUDY

Major Field: Exercise Physiology

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INTRODUCTION

Among the physiologic changes closely correlated with the long-term chronic performance of exercise is the reduction of relative and absolute quantities of body fat in adults and children. (30,115,140) Indeed, the regular participation in exercise of even moderate proportions is frequently recommended as a strategy to reduce or maintain body fat at relatively low levels. (7,31,45,84,97,111,122,132)

It is well documented that all forms of exercise, to be sure all human movements, are metabolic energy consuming events (56,67,81,91,126,133), with the expenditure of approximately thirty-five hundred kilocalories equivalent to the utilization of .45 kilograms, or one pound, of fat.(133) This is particularly important in long term steady-state submaximal aerobic exercise in which fat acts as the primary source of energy.(100)

It is equally well documented that metabolic rate, and resultant body temperature, increases during the performance of physical activities. (1,4,14,15,22,32,46,58,93,112,114) These rates of increase are approximately proportional to the intensity of aerobic exercise as well as the duration of activity and fuel metabolized.

(4,14,107) Owing to the thermogenic and oxidative events of energy utilization in metabolically active tissue, the rates of metabolism and energy expenditure in the human body have been determined to be accurately assessed from direct measurement of total body heat production and indirectly by measurement of oxygen consumption during exercise as well as at rest.

(5,7,11,22,32,33,34,93,104,112)

The expenditure of energy occurring during the performance of exercise, as well as non-exercise, activities has been quantified directly and indirectly on the basis of time and intensity of exercise performance as well as on the basis of energy expended per volume of active muscle mass. (12,74,85,108,111,116) These various classifications indicate that the performance of the extensive list of possible exercise and non-exercise activities can vary markedly in terms of energy expenditure. The extreme variability in energy utilization between the various forms of exercise has been attributed primarily to the size of the muscle mass involved in the activity, the intensity and duration of exercise performance, and the aerobic/anaerobic involvement of the exercise.(7,84) Owing to the relative ease of quantifying these parameters running is among the simplest forms of exercise for which energy expenditure can be assessed.

In addition to the substantial information collected

concerning metabolic energy expenditure during exercise performance, landmark investigations have also elucidated the energy expending events of the oxygen debt recovery period occurring immediately post-exercise. (71,72,73,81) These adjustments are substantially energy consuming and include recovery from lactate accumulation and replenishment of phosphogen concentrations in metabolically active tissues.(81)

Indeed, high levels of metabolic energy expenditure does not end with the cessation of exercise. Beginning with studies conducted in the previous century which detailed what was then termed "fever of overexertion" (88,92,118,124), an elevation in resting post-exercise metabolic rate and body temperature has been found to be sustained for many hours post-exercise and cannot be directly or wholly attributable to lactacid/alactacid recovery.(141) In this regard, Murlin and Burton (1935) indicate that not all metabolic activity of the body is oxidative in nature. According to pioneering investigations by Benedict, Cathcart, and Carpenter (16,17,18,19,20,21), Herxheimer, Wissing, and Wolff (1926) and Edwards, Thorndike and Dill (1935) and reaffirmed by deVries (1963) in a subsequent investigation, post-exercise metabolic rate may remain elevated from six hours up to forty-eight hours after even a mild aerobic exercise bout. Allen and Quigley (1977) indicate that post-exercise

metabolic rate may have a sustained elevation of from ten to twenty percent above pre-exercise resting levels.

To be sure, energy expended in the hours after even "mild to moderate" exercise significantly contributes to the energy expenditure of a bout of exercise.(122) Allen and Quigley (1977) indicate that post-exercise energy expenditure may be equivalent to the energy expended during the performance of the exercise bout itself, thus effectively doubling the contribution of exercise to the utilization of energy by the body and subsequent reduction in body fat. Indeed, the effect of exercise may be to transiently alter upward what has come to be termed the body's metabolic "set-point" resulting in greater total energy expenditure.(87)

In previous studies the effect of exercise on post-exercise metabolic rate has been examined primarily from the perspective of the effects of utilizing prolonged endurance exercise or intermittent sporting activities (i.e. football, lacrosse) of unspecific intensities to stimulate changes in metabolic rate. Of these previous studies, Benedict and Carpenter (1910) examined the post-exercise effects of subjectively determined "moderate, severe, and very severe" strenuous work on energy utilization. These investigators assessed total body heat production beginning seven hours after exercise cessation to determine total body energy utilization. The results of

their study indicate that post-exercise resting metabolic rate tended to increase with the severity of intensity of exercise performance.

Despite the efforts of these investigators, however, the issue of the effects of severity of intensity of exercise performance on post-exercise metabolic rate and subsequent metabolic energy utilization remains unresolved. This lack of clarity is attributable to the absence of a quantified definition of severity of exercise intensity in the previous study. It is apparent, therefore, that to more specifically understand the effects of various intensities of exercise on post-exercise metabolic rate and concomittant energy utilization a quantifiable measure more reliable than subjective observation must be employed in the administration of exercise bouts that preceed post-exercise metabolic assessment.

Purpose of the Study

Generally, the purpose of this study is to investigate the total energy costs to the human body of a bout of treadmill running exercise performed at a specific degree of exertion in order to completely assess the effects of exercise intensity on the total utilization of metabolic energy which results from that exercise performance.

Specifically, the purpose of this study is to:

A. assess the effects of twenty minutes of treadmill running on post-exercise metabolic rate and heart rate,

and;

B. assess the individual effects of two separate treadmill running intensities, 25% and 75% of maximal oxygen consumption on:

1) the degree of change in post-exercise resting metabolic and heart rates over pre-exercise metabolic and heart rate values, and;

2) the period of time over which any changes in post-exercise resting metabolic and heart rates endure before pre-exercise resting metabolic and heart rate levels are re-established.

Hypotheses of the Study

Ho 1 : There will be no difference in the resting metabolic rate between the Control and 25% and 75% treatments of the Experimental groups.

Ho2 : There will be no difference in the metabolic rate between males and females in the Control group and 25% and 75% treatments of the Experimental group.

Ho3 : There will be no difference in the degree of change in resting metabolic rate from pretest to posttests which result from twenty minutes of treadmill running exercise at either 25% or 75% of maximal oxygen consumption.

Significance of the Study

Potential benefit to mankind in general. Mankind may benefit from this study by the knowledge that intensity of exercise does or does not significantly affect

post-exercise resting metabolism in individuals, and does or does not affect resultant energy use in the human body. The potential for such information would be of most applicable value in the control of total body weight and possibly overfatness in individuals that tend toward this condition.

Potential benefit to the individual subject. All personal individual results of all tests performed in this study will be made available to each subject. The subject will benefit from the knowledge of the quantified information about his/her physical health as determined by:

- A. a comprehensive medical examination;
- B. a resting, exercise and recovery evaluation of the electrical activity, rate, and rhythm of the subject's heart;
- C. in some cases measurement of the subject's ability to consume oxygen before, during and after exercise, and;
- D. measurement of the effects of exercise on the subject's post-exercise resting metabolic and heart rates.

The individual results of this study may be utilized by the subject, his/her family, and/or medical doctor to aid in the assessment of the subject's current state of health, cardiovascular fitness and metabolic activity as it affects the subject's level of physical fitness.

Delimitations of the Study

The results of this study, while having possible

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benefit to populations outside that which is represented in the study sample, are primarily applicable to that population which:

- A. is non-obese
- B. do not chronically exercise aerobically
- C. are between the ages of eighteen and thirty years
- D. have no current clinical level medical problems
- E. are not currently consuming any form of medication, other drugs or recreational stimulants including caffeine, and;
- F. are non-tobacco users

Limitations of the Study

The results of this study are limited by certain physical, personnel and operational constraints which include:

- A. Pre-exercise resting metabolic rate was measured over a twenty minute period.
- B. The treadmill running exercise bouts were administered over a twenty minute period.
- C. While all subjects were not currently chronically training aerobically, some subjects maintained relatively better states of aerobic fitness throughout the course of the study. Subjects more adapted to aerobic exercise stress may have recovered more efficiently metabolically during recovery from the exercise bout. Therefore, the same metabolic recovery profile may not have been exhibited in

the more trained subjects as in by the lesser trained⁹ subjects.

D. Throughout the course of the experimental period absolute control over the training activities of all subjects was not possible.

E. Between the post-exercise assessment intervals of three hours, six hours and twenty-four hours on test days the subjects were instructed not to perform any strenuous physical activity, consume any medication, alcohol, stimulants, or large quantities of food with high fat or protein content throughout the duration of the testing period. However, absolute control of the subjects activities was not possible throughout this time period.

F. Post-exercise assessment of resting metabolic rate was followed for only twenty-four hours after exercise.

G. During the testing session, immediately following all twenty-minute treadmill running periods, approximately three minutes were required to transfer each subject from the treadmill into the whole-body calorimeter. Therefore, the metabolic activity of the body during this transfer time period was not recorded.

H. The time of day of metabolic assessment of varied from subject to subject in accord with the subjects availability.

I. Metabolic rate as determined by heat production while lying supine in a whole body calorimeter while

expired lung volumes were collected directly from the¹⁰
subjects mouth and routed to air collection bags outside
the calorimeter during the Calorimeter Validation Study.

Definition of Terms

A. Whole body calorimeter-an instrument to assess heat loss from a supine human body. The purpose of the calorimeter is to directly assess metabolic rate. The calorimeter utilized in this study is a Basal Tech Whole Body Calorimeter. Further detailed description of this instrument can be found in the Apparatus and Methodology Chapter and in Appendixes A and D.

B. Resting metabolic rate-an assessment of the metabolic energy, in kilocalories per hour, utilized while at supine rest for twenty minutes, after a previous twelve hour fast. Resting metabolic rate was determined directly by heat production measured in the Basal Tech Whole Body Calorimeter and indirectly by oxygen consumption measurement in the Calorimeter Validation Study associated with this research.

C. Post-exercise resting metabolic rate-an assessment of the metabolic energy, in kilocalories per hour, utilized while at rest in a supine position following exercise at intervals of zero, three, six, and twenty-four hours post-exercise. Post-exercise resting metabolic rate was assessed utilizing the same measures identified for pre-exercise resting metabolic rate.

D. Exercise intensity-a percentage, twenty-five¹¹ or seventy-five percent, of a predetermined or predicted maximal oxygen consumption utilized to establish the exercise workload on the subject during the treatment phases of the Exercise Intensity Study.

REVIEW OF THE LITERATURE

The effect of exercise has been known for nearly a century to elevate body temperature during the period of time immediately following an exercise period. As reported in Haight and Keating (1973), Rendon (1889), Knott (1888), and Peter (1889) all referred to post-exercise elevation in body temperature as "fatigue fever", attributing such temperature elevation to a state of exhaustion that existed as a result of exercise. It is interesting to note that, according to Haight and Keating (1973), all of these assessments were made without the investigators actually recording a sustained elevation in temperature after exercise.

In 1911 Bardswell and Chapman investigated the effects of muscular exertion on normal pre-exercise and post-exercise body temperature. These investigators, using rectal temperature, found a consistent and constant rise in internal temperatures up to 103° F and 105° F in some instances, initiated by varying intensities of muscular effort. Given the daily variations in body temperature, the effects of exercise exertion induced temperature rise was found to be consistent and predictable at all times of the day given the degree of

exercise performed. The greater the intensity of exertion¹³ the more marked the rise in temperature. Maximal temperature rise was achieved in all instances in this study after forty-five to sixty minutes of exercise, remaining stable thereafter. As measured rectally, these investigators found that internal temperature fell to within normal values within sixty minutes of exercise cessation.

Downey and Darling (1962) also found significant elevations in rectal temperatures after twenty to forty-five minutes of exercise. These investigators concluded that, as temperature rise post-exercise was unmodified any dosage or time of consumption of salicylates during or after exercise, rise in body temperature was probably not attributable to any pyrogenic substance related to exercise as seen in pathological states which induce fever. Rather, during exercise temperature rise is mediated by some control mechanism associated with normal metabolism. Downey and Darling (1962) conclude, however, that the fall in body temperature post-exercise is the result of a mechanism different from that which induce the rise in temperature. These investigators indicate that rectal temperature had not returned to pre-exercise resting levels even after forty-five minutes recovery. These investigators and others(4,15,126) indicate that body temperature elevation

during moderate exercise does not appear to signify a¹⁴ physiologic difficulty in heat elimination since the same elevation is seen in trained, acclimitized, and well hydrated individuals whether exercised in hot, cold, or temperate environments.

Woods and Mansfield (1904) in a dietary study of Maine lumbermen engaged for long periods of time in various severe, yet unquantified, occupation related work tasks in a constantly cold outdoor environment found a daily energy exchange of more than 5,000 to 8,000 kilocalories in these individuals. During the many week long work periods while copious food was consumed by the lumbermen no gain in their body weight was recorded. Indeed, a reduction in food consumption due to a regularly missed meal resulted in sever weight loss in some lumbermen. The work performed in this in-site study was periodic, lasting from early morning to late evening of each day. Indeed, the lumbermen were not constantly called upon to perform work at severly high levels of sustained effort. However, when performed the workers' strenuous muscular activity did result in significantly elevated metabolic rates which were sustained long after work activity has ended.

Benedict and Carthcart (1913) reported a substantial increase in post-exercise basal metabolic rate, obtained while reclining, after five to six hours of "severe"

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although unquantified muscular work. After cessation of the work activity metabolism exhibited a prolonged, although steadily decreasing, influence of the preceding muscular activity. In this study a male subject whose pre-exercise basal metabolism utilized 1.15 kilocalories per minute was elevated on average approximately .2 kilocalories per minute after riding a bicycle for seventy-four minutes. Benedict and Carthcart attributed this increase in metabolism to some undefined stimulus to cellular activity that persisted for an extended period after all evidence of previous muscular activity had ceased, even as distant as activity which had occurred the preceding day.

Loewy (1889), Zuntz and Schumberg (1901) and Speck (1926) did not concur in the findings of the previous studies which reported elevations in post-exercise resting metabolic rates after prolonged exercise. The variances in results of these studies from those previously reviewed which indicated elevation of resting metabolic rate post-exercise may be attributable to the submaximal, non-exhausting character and duration of the exercise performed.(70)

Edwards, Thorndike and Dill (1935) reported that college age football players maintained stable body weight throughout a competitive football season while consuming an average 5,600 kilocalories daily. Attributing the use of

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approximately half this energy input to the daily costs of basal metabolism (approximately 2000 kilocalories) and light daily activity (800 kilocalories) plus an additional loss of energy (300 kilocalories) through urine and feces, these investigators concluded that roughly 2500 kilocalories were either directly or indirectly attributable to the daily playing of football. Further, these investigators determined that the direct actual cost of playing or practicing football over a two-hour period was on average approximately 1250 kilocalories in their subjects. These investigators conclude, therefore, that approximately 1200 kilocalories, or greater than twenty percent of total daily energy intake, was indirectly attributable to the playing of football. This additional energy utilization, these investigators conclude, resulted from an increase in metabolic rate in active tissues that was initiated during exercise and persisted for up to fifteen hours after a game or strenuous practice was completed. Metabolic rate returned to pre-exercise levels during the post-exercise period slowly and asymptotically. Edwards, Thorndike and Dill attributed only a small fraction of the post-exercise energy consumption to the post-exercise metabolic requirements of lactic acid, and presumably alactic acid, components of oxygen debt incurred during exercise. In this study lactate and alactate levels were observed to

"promptly" return to pre-exercise resting levels while¹⁷ resting metabolic rate remained elevated. Finally, in a similarly conducted study of lacrosse athletes these same investigators found post-exercise resting metabolic rates to be twenty-three and eight percent above normal thirteen and thirty-one hours, respectively, after completion of exercise.

Other investigators have found results observed above. Utilizing non-graded strenuous exercise Jaquet (1910) found an unspecified increase in basal metabolic rate thirteen hours post-exercise. Hill, Long and Luppin (1924) found after lactate recovery from a ninety-minute bout of exercise a continued seven percent increase in basal metabolic rate. These investigators also attributed the observed sustained elevation in oxygen consumption, and concomittant metabolic rate, to a continued stimulation to active muscle tissue.

Herxheimer, Wissing, and Wolff (1926) studied the effects of prolonged exhausting skiing exercise of 160 minutes and increasing elevation on post-exercise basal metabolic rate, although exercise intensity was unquantified. Post-exercise metabolic rate was assessed by measurement of post-exercise oxygen consumption. These investigators found significant increases in oxygen consumed at rest from pre-exercise to post-exercise, 10% to 14.9%, which persisted for between thirty-six to

forty-eight hours after exercise cessation. In this ¹⁸ study, while chronic long-term training induced a chronic elevation in basal metabolic rate in subjects, these investigators concluded that a single bout of exhaustive exercise was even more influential in elevating and maintaining post-exercise basal metabolic rate.

Benedict and Carpenter (1910) investigated the post-exercise effects of subjectively determined "moderate, severe, and very severe" strenuous work on metabolic energy utilization. These investigators employed assessment of body heat production in a whole-body calorimeter, as well as assessment of oxygen consumed and carbon dioxide produced, as measures of energy utilization. The results of this study indicate that post-exercise basal metabolic rate, as measured during sleep, tended to increase with an increase in the severity of exercise. Measurement of metabolic rate, in this investigation, began seven hours after the cessation of exercise during sleep. The investigators of this study did not provide information as to how they quantified the various intensities of exercise and the degree of aerobic and/or anaerobic involvement in the exercise. In addition, these investigators did not provide information as to the duration of the various work bouts and, indeed, the mode of exercise employed to induce elevations in post-exercise metabolic rate. Finally, peak post-exercise

resting metabolic rate was not assessed in this study,¹⁹ which normally would occur immediately post-exercise. Rather, seven hours elapsed between the end of the exercise bouts and the initial measurement of post-exercise metabolic rate, leaving unanswered a question of the rate of decay from maximal values to pre-exercise resting levels of metabolic rate.

In a 1963 study of the "after effects of exercise upon resting metabolic rate", conducted by deVries and Gray, a 7.5 to twenty-eight percent increase in post-exercise metabolic rate was found four hours after cessation of a "vigorous workout" than was observed at the same time of day on control non-exercising days. This increase in metabolic rate was observed to be sustained for six hours post-exercise.

In a review of exercise and post-exercise effects in the control of obesity, Allen and Quigley (1977) support the contention that although the actual performance of a vigorous physical activity has a discreet energy requirement, the increase in post-exercise resting metabolic rate over the subsequent hours and days post-exercise may account for an energy expenditure which may be as great as the cost the performance of the activity itself. These authors indicate, therefore, that the actual total costs of physical exercise may be as high as twice the costs commonly attributed to vigorous

exercise. While these authors indicate that endurance type exercise is of preference in controlling obesity, no mention is made in this regard as to the duration of exercise and the severity of exercise intensity of preference.

Finally, according to Webb, Annis, and Troutman (1980) measurements of energy balance between indirect and direct methods of calorimetry varied according to amounts of sleep, exercise, and dietary intake. The range of measurements of energy balance between indirect and direct calorimetry was the smallest during twenty-four hour periods of rest. The greatest variances in measurement of energy balance occurred when subjects experienced sleeplessness, took part in prolonged exercise bouts, and consumed caloric amounts less than metabolically expended.

In summary, there is a general consensus in the literature that resting metabolic rate increases post-exercise with an accompanying increase in thermogenesis. This consensus was derived using both direct and indirect calorimetry. Some unresolved ambiguities exist, however, concerning the mode, duration, and intensity of the exercise bout which preceded measurement of metabolic rate. Indeed, the early conflict as to whether or not there was a rise in metabolic rate post-exercise seems to be related to how prolonged and severe the exercise treatments were in each study. More

recent studies, however, seem to confirm the rise in ²¹
post-exercise metabolic rate with a degree of variance in
metabolic measures differing widely with the mode of
calorimetry utilized. A case, therefore, can be made for
conducting a study designed to clarify the specific
effects of exercise intensity and/or duration on
post-exercise metabolic rate as well as the degree of
variance of metabolic measurement between direct and
indirect methods of calorimetry.

METHODOLOGY/APPARATUS

Exercise Intensity Study

Research Plan

A. Description of Subject Selection

The population sample was composed of fourteen males and twelve females. Eight males and seven females were randomly assigned to the Experiment group and six males and five females were randomly assigned to the Control group. All subjects were volunteers and of college age between nineteen and thirty years old. All subjects were in good health as determined by a medical doctor's examination and exhibited no clinical manifestations of current or potential illness or disorder. All subjects were non-tobacco users and were not consuming any medication or other recreational drugs, including caffeine, during the testing period. So as to minimize the influence of extraneous and uncontrolled physical training influences all subjects had not participated in a regular aerobic exercise training program at least six months prior to participation in the study. In addition, all subjects agreed not to the participate in any strenuous aerobic or anaerobic exercise for at least

twenty-four hours prior to each testing session. No²³ remuneration was given to any subject for participation in the study other than a report to each subject of their own individual tests results.

B. Experimental Design

Eight men and seven women were studied on two independent occasions, approximately five days apart, to determine the effects of two different twenty-minute treadmill running intensities on the degree of change and time of duration of change of post-exercise resting metabolic rate. Procedurally, all treatment subjects first reported personal and family medical histories. Each subject was then physically examined by a medical doctor to determine suitability for participation in the study. Each qualified subject was then tested twice to determine resting and exercise values for heart rate, heart rhythm, and heart electrical conductance activity utilizing a seven lead electrocardiograph. Simultaneously, resting and exercise levels of diastolic and systolic blood pressure and maximal oxygen consumption were assessed. The linear relationship between heart rate and oxygen consumption for submaximal workloads for each subject were then titrated to determine heart rate equivalents of 25% and 75% values of maximal oxygen consumptions.

Each treatment group subject was then subsequently on two separate independent occasions, approximately five days apart and after a twelve-hour fast, assessed for pre-exercise resting metabolic rate. This was determined by total body heat production as measured while reclined for twenty minutes in a whole-body calorimeter until a stable internal/external calorimeter value was established. Pre-exercise resting heart rate was also monitored during this period. After pre-assessment of resting metabolic rate, on each occasion and utilizing the previously titrated heart rate/oxygen consumption values, each subject then engaged in a twenty-minute bout of treadmill running exercise at either approximately 25% or 75% of maximal oxygen consumption. The titrated heart rate values were utilized in all tests as estimates of the target oxygen consumption values. For verification purposes oxygen consumption was assessed during each treatment test period, although calculation of oxygen consumption was not possible during the testing session. All subjects exercised at each intensity of exertion on two separate independent days.

Immediately following completion of each twenty-minute bout of exercise each Experimental group subject was then assessed for post-exercise metabolic rate utilizing total body heat production in the same manner previously described for assessment of pre-exercise

metabolic rate. This measure was assessed while the ²⁵ subject was reclined in the whole-body calorimeter. Total time of the post-exercise metabolic assessment period on each occasion was twenty-minutes. Post-exercise heart rate was also monitored during this post-exercise time period. Finally, post-exercise heat production and heart rate were again assessed, utilizing the same procedures defined above, three, six and twenty-four hours post-exercise.

A Control group composed of six men and five women were assessed over the parameters and followed the same procedures and time schedule described above for the Experimental group. These individuals, however, did not participate in any form of strenuous exercise throughout the entire testing procedure.

C. Personnel

The Personnel involved in the administration of the procedures outlined in this study were:

1. the investigator
2. a medical physician with a specialization in pulmonary medicine
3. a laboratory technician with specialization in graded exercise testing, cardio-pulmonary resuscitation, and electrocardiography
4. a laboratory assistant specifically trained by

the investigator in the measurement of metabolic rate²⁶
utilizing the Basal Tech Whole Body Calorimeter, as well
as administration of graded exercise tests.

D. Apparatus/Methodology

The following procedures, time schedule, and calender
were closely adhered to and administered by the
investigator, associated technicians, and/or associated
medical doctor to each and all individual subjects
participating in this study:

1. Subject Medical Examination

Each treatment group subject was given a
preliminary medical examination by a medical doctor
associated with the study prior to participation in any
other aspect of the study. The medical examination was
administered immediately prior to each subject's initial
test for maximal oxygen consumption. The medical
examination included:

- a) a personal and family history of any
cardiovascular disease or disorders, orthopedic disorders,
and any other problems which may have precluded an
individual's participation in the study;
- b) auscultation of heart and lung sounds;
- c) examination for any current disease states;
- d) a supine resting and standing seven lead

electrocardiogram utilizing a Hewlett-Packard 1500 B Electrocardiograph with five hollowed lead disk electrodes and a Hewlett-Packard Oscilloscope (Model 7803 B);

e) supine resting and standing diastolic and systolic blood pressure measurement utilizing a Py-Matt Trimline sphygmomanometer and adult cuff, and;

f) any other procedure appropriate for any given individual by the examining associated medical doctor.

2. Test for Maximal Oxygen Consumption

The purpose of the test for maximal oxygen consumption was to assess an individual subject's maximum metabolic and heart rates, as well as systolic and diastolic blood pressure responses to progressively increasing intensities of treadmill running exercise. In this test maximal values for oxygen consumption are attained when the above parameters are maximally stressed and cease to be influenced by further increases in exercise workload.

All subjects were individually monitored in the above parameters at rest prior to exercise, throughout a twenty-minute running exercise bout, as well as during recovery from the exercise bout by the investigator, associated technician, and/or associated medical doctor. The test for maximal oxygen consumption was administered on a Collins variable speed and grade treadmill. The

subjects' running speed and grade were governed by treadmill speed and elevation. Timing of all events of this procedure were kept utilizing a Gra Lab Universal Timer, Model 171. The protocol for administration of the test for maximal oxygen consumption was conducted in accordance with the following modified procedures outlined by R.A. Bruce, et. al. (1971). The procedure for conducting the test for maximal oxygen consumption went as follows:

a) each subject's weight was assessed to the nearest half-pound;

b) the initial treadmill speed for the test for maximal oxygen consumption was three miles per hour with a zero degree grade elevation. This workload was maintained as a warm-up period for the first three-minutes of the treadmill running exercise bout;

c) the exercise workload was then increased every three minutes throughout the test for maximal oxygen consumption by increasing treadmill speed by one mile per hour and treadmill grade by two percent or 1.5 degrees until maximal oxygen consumption or volitional fatigue occurred.

During the test for maximal oxygen consumption expired respiratory gas volumes were collected after five minutes rest, for one-minute during each collection, in a Collins Tissot 120 L20 liter gas meter and for every other

minute thereafter throughout the exercise bout. A ²⁹
Modified Otis-McKerrow two-way breathing valve designed
for collecting expired air and equipped with a Collins
flanged mouthpiece was utilized to mix and collect the
expired air. The subjects were equipped with the
mouthpiece and nose clip for the last minute of rest and
throughout the exercise bout as well as during the
recovery period. The mouthpiece and two-way breathing
valve were supported by a head harness and in some cases
by an adjustable external brace for the comfort of the
individual subjects. The two-way breathing valve was
connected to a one-hundred and fifty centimeter long, four
centimeter diameter metal wire reinforced plastic tube to
permit collection of expired air in the Collins Tissot 120
L20 gas meter. Minute expired gas volumes were collected
and measured in the Collins Tissot instrument. Tissot air
temperature was monitored by a top cylinder mounted
thermometer.

Expired end tidal volume oxygen and carbon dioxide
concentrations were monitored with each breath at the
mouthpiece on the Modified Otis-McKerrow two-way breathing
valve as well as every other minute in the mixing chamber
of the Collins Tissot via oxygen and carbon dioxide
sensors connected to a Perkins-Elmer Medical Mass
Spectrometer. All gas collections were determined as a
percentage of the total expired gas and in terms of

absolute volumes per breath. Ambient temperature, 30
pressure, and concentration of expired gas water
saturation were measured and recorded. Minute oxygen and
carbon dioxide concentrations and volumes were then
utilized to compute minute values for oxygen consumption
utilizing a pre-programmed Commodore 64 computer. All data
was there permanently stored and then utilized to
calculate 25% and 75% of maximal oxygen consumption. The
linear relationship of oxygen consumption was then
titrated with exercise workload heart rate for each
individual subject to determine heart rates which
corresponded with 25% and 75% of maximal oxygen
consumption. Since instantaneous determinations of oxygen
consumption were not possible to calculate during an
exercise test the pre-determined target heart rates were
then subsequently utilized in succeeding tests to estimate
appropriate exercise intensities. That is, heart rate was
utilized to estimate 25% and 75% submaximal values of
maximal oxygen consumption in each of the two independent
treadmill running exercise treatment bouts.

3. Heart rate and rhythm

Heart rate and rhythm were monitored and recorded
utilizing a Hewlett-Packard 1500 B Electrocardiograph and
Oscilloscope, Model 7803 B after five minutes of supine
rest and while standing immediately prior to

administration of the tests for maximal oxygen consumption. Heart rate and rhythm were then monitored throughout the treadmill running exercise period and during recovery from exercise until heart rate returned to within twenty beats of pre-exercise resting levels. Recordings of heart rate and rhythm were made the last ten seconds of each minute throughout the test.

During all treadmill running exercise, both during administration of the two tests for maximal oxygen consumption and the two subsequent independent twenty-minute treadmill running exercise bouts at 25% and 75% of maximal oxygen consumption, heart rate was continually monitored by the Hewlett-Packard Oscilloscope, Model 7803 B utilizing lead V5. In the standing, running exercise, and recovery positions all subject chest electrodes were secured with an elastic bandage body wrap.

4. Blood Pressure

Diastolic and systolic blood pressures were monitored and recorded at the end of the five minute pre-exercise rest period, while standing at rest, the last twenty seconds of every other minute, when possible, during treadmill running exercise, and during every other minute of recovery from exercise. A Py-Matt Trimline sphygmomanometer with an adult cuff and stethoscope were

utilized to monitor this parameter.

5. Pre-exercise Metabolic Assessment

Immediately prior to each of the two twenty-minute treadmill running exercise bouts at 25% and 75% of maximal oxygen consumption each subject was assessed for pre-exercise resting metabolic rate utilizing a Basal-Tech Whole Body Calorimeter to assess total body heat production.(136) The Basal Tech Whole Body Calorimeter is an instrument in which a subject lies supine for the purpose of assessing resting metabolic heat production. When in operation, the calorimeter is a sealed six-sided rectangular box approximately seven feet in length, three feet high and three feet in width. It is constructed of one-quarter inch thick clear plastic sheeting. Ambient temperature room air is pumped into the calorimeter and down its length through a porthole approximately six-inches in width. Air exits the calorimeter at the opposite end to the air pump through another porthole equipped with a digital thermometer in the air flow path.

To attain resting metabolic rate with this instrument a subject reclines in the calorimeter for approximately twenty to thirty minutes or until three similar metabolic measurements are attained. Ambient air temperature is simultaneously measured. The difference between internal calorimeter temperature and ambient temperature is then

utilized to calculate metabolic rate. Figure 1 of Appendix A utilizes the temperature difference to determine kilocalories expended per hour by the subject and Figure 2 of Appendix A utilizes the subject's weight to calculate its additional effect on metabolic rate. The calculation of metabolic rate from the utilization of the Basal Tech Calorimeter is illustrated in the text of Appendix A. (Calorimeter validation model, validation-App.D)

Heart rate and rhythm were also monitored during this pre-exercise metabolic assessment period with the previously described apparatus. All parameters were measured until consistently stable values were achieved or for approximately twenty-minutes prior to exercise.

6. 25% and 75% of Maximal Oxygen Consumption Treadmill Running Exercise Bouts

Two separate and independent twenty-minute treadmill running exercise bouts conducted at either 25% or 75% of maximal oxygen consumption were administered on a Collins variable speed and grade treadmill. Heart rate, whose linear relationship with oxygen consumption had been previously titrated based upon the highest values achieved during the two preceding tests for maximal oxygen consumption and heart rate, were utilized to estimate the previously established target percentages of maximal oxygen consumption for each exercise bout. The

investigator and a medical doctor associated with the³⁴
study visually, and when possible, verbally monitored the
physical status of each subject throughout each exercise
bout.

7. Post-exercise Metabolic Rate Assessment

Following each treadmill running exercise bout each subject re-entered the Basal-Tech Whole Body Calorimeter and assumed a resting supine position. Post-exercise resting metabolic rate was then continually assessed. As in the pre-test total body heat production was determined based upon air temperature differences between forced ambient air incoming to the whole body calorimeter and passing over the reclining subject and heated outgoing air exiting the instrument. Immediate post-exercise measurement of metabolic rate occurred during the first twenty-minutes after cessation of exercise. Identical twenty-minute assessments of metabolic rate were conducted for twenty-minutes three hours, six hours, and twenty-four hours after the cessation of exercise. The purpose of the four post-exercise metabolic assessments was to determine any changes in post-exercise metabolic rate from pre-exercise levels, to determine the duration of any metabolic changes, and to follow the rate of decay of any changes back to pre-exercise levels. Heart rate was identically

monitored and recorded throughout each of the twenty-minute metabolic assessment periods.

8. Percent Body Fat Determination

Percent body fat for males was calculated according to the procedures of the Brozek formula utilizing skinfold and anthropometric diameters (28), utilizing the Forsyth and Sinning formula for body density (50). Percent body fat for females was determined utilizing the Sloan, Burt, Blyth formula (129).

E. Analysis

Utilizing the computer programs of the Statistical Package for Social Studies of the Ohio State University Baker Systems Computer Center, a multivariate analysis of variance (MANOVA) computer program was employed to determine any significant differences between the means of the pre-exercise and repeated post-exercise resting metabolic rates for each Experimental group treatment, 25% and 75% of maximal oxygen consumption treadmill running exercise and Control group. The same statistical program was utilized to determine any significant differences attributable to the influence of sex and subject group on metabolic rate. Also, the same statistical program was utilized to detect any interaction effects on mean metabolic rate of the main variables, subject's group and treatment, sex, and time of metabolic assessment.

Calorimeter Validation Study

Owing to the newness of the Basal Tech Whole Body Calorimeter and relative lack of data comparing this instrument to other previously validated methods of metabolic rate determination, it seemed prudent to conduct a study to establish the degree of agreement between the metabolic rates derived from this new instrument and the oxygen consumption method of metabolic rate assessment.

A. Subjects

A sample of five randomly selected males participated in the Calorimeter Validation Study. These subjects were selected from the identical pool of potential volunteers from which the Exercise Intensity Study subjects were selected. These subjects, therefore, were quite homogeneous in characteristics with the subjects of the previously described study. Indeed, one subject participated in both studies. All subjects in this study met all the medical and participation criteria established for males of the Exercise Intensity Study.

B. Design

Pre-exercise resting metabolic rate of each male subject was assessed after a twelve hour fast utilizing

two methods of evaluation, the Basal Tech Whole Body³⁷ Calorimeter and the oxygen consumption method.

Immediately subsequent to this assessment each subject exercised to fifty percent of his predicted maximal oxygen consumption capability for twenty minutes utilizing a bicycle ergometer. Immediately following this event each subject was again reassessed for resting metabolic rate utilizing the above named evaluation methods.

C. Methodology and Apparatus

Body weight of each subject was determined to the nearest half pound. Pre-exercise resting metabolic rate was assessed utilizing the Basal Tech Whole Body Calorimeter and the oxygen consumption method simultaneously. The procedures for use of the calorimeter were previously described in the methodology segment of the Exercise Intensity Study. Since, however, oxygen consumption while at rest was also measured at the same time specific modifications to the procedures and apparatus were required. Specifically, in terms of apparatus, the subject was upon entry into the calorimeter required to insert a mouthpiece designed to collect expired air into his mouth. This mouthpiece was connected to the Modified Otis-McKerrow two-way breathing valve previously specified which was subsequently attached to a two-foot long section of metal wire re-enforced 4

centimeter diameter tubing. This tubing was then connected to a 300 gram meteorological balloon design for collecting expired air. This balloon was located outside the calorimeter while the subject laid in a supine position in the instrument (see Appendix B for the specific design of this apparatus). A small (approximately 5 centimeters) section of the calorimeter rubber lid seal was necessarily removed to accomodate the exit of the tubing from the inside of the calorimeter to the meteorological balloon outside. All gaps were sealed around the tubing to prevent any air or heat loss in this manner.

Pre-exercise and post-exercise resting expired air collections were made for two minutes in the balloons throughout each of the twenty-minute evaluation periods. Utilizing a 100 milliliter Yale hypodermic syringe with three-way stopcock value, a fifty milliliter sample of mixed expired air was taken from each balloon and subsequently analyzed for oxygen and carbon dioxide concentration. These latter assessments were made utilizing a Beckman oxygen analyzer and a Beckman carbon dioxide analyzer. Ambient air temperature and pressure were noted and remaining meteorological balloon collections were measured utilizing a Parkinson-Cowan gas flow meter. The oxygen consumption, respiratory quotient, and metabolic rate in kilocalories per hour were then

calculated.

The fifty-percent of predicted maximal oxygen consumption was administered on a Crescent-Monarch variable resistance bicycle ergometer following a protocol that required them to peddle at fifty revolutions per minute. Resistance was initially set at 0 kiloponds for the first two minutes and then increased every three minutes by 300 kiloponds until fifty-percent of predicted maximal oxygen consumption was achieved and was there maintained throughout the exercise period. Heart rate was also monitored throughout the exercise period in the manner previously described in the exercise sessions of the Exercise Intensity Study. Maximal heart rate was predicted from age and, utilizing this heart rate as well as exercise workload, maximal oxygen consumption was estimated utilizing the Astrand-Ryhming nomogram for prediction of oxygen consumption.(6)(See Appendix C) Fifty-percent of this estimated value was utilized to set workload for each subject. Descriptive data of the results of this study are listed in Table 10.

D. Analysis

A Pearson product-moment correlation coefficient statistical program of the previously stated Statistical Package for the Social Sciences (SPSS) was utilized to compare the relationship between the Basal Tech Whole Body

Calorimeter determined metabolic rates and those determined by the oxygen consumption method. The results of this study are located in Table 11.

Also, a multivariate analysis of variance was utilized to compare the pre-test and post-test pairs of scores of each subjects Basal Tech Whole Body Calorimeter and oxygen consumption method derived metabolic rates in kilocalories per minute.

Human Subjects Clearance

Approval of the design and procedures of this study was granted by the Human Subjects Review Committee of the Ohio State University. This study is catalogued by this committee as number 83H0034.

RESULTS

Exercise Intensity Study

Descriptive Data

Descriptive data for all twenty-six subjects are included in Tables 1 and 2 , data for the Experimental group subjects in the former table and Control group data in the latter. Each individual's sex, age, weight, height, percent body fat, maximum oxygen consumption, maximum heart rate, and resting heart rate are specified in these tables. The study sample was quite homogeneous with regard to the above characteristics. This can be attributed to the nature and degree of intensity of activity required of study participants. All volunteer subjects were informed previous to participation in the study of the high degrees of exertion anticipated during exercise performance. This undoubtedly biased the study sample, tending to limit the volunteerism of potential study candidates which were underconditioned or overweight.

Experimental Data

Tables 3 , 4 , and 5 list experimental data derived

Table 1
Exercise Intensity Study
 DESCRIPTIVE DATA
Experimental Group

Subject	Sex	Age	Weight kilograms	Height inches	% Body Fat	$\dot{V}O_2$ Max l/min*	MaxHR B/min	RestHR B/min
1	M	20	89.72	73.0	16.1	5.75	205	43
2	M	21	95.68	70.0	12.3	6.16	215	60
3	M	25	69.54	67.5	8.5	6.19	200	35
4	M	21	71.36	69.2	15.3	4.74	220	62
5	M	28	89.09	71.0	18.2	5.31	195	45
6	M	21	80.00	70.5	11.7	5.47	190	55
7	M	22	91.13	70.5	12.1	4.78	200	50
8	M	27	80.00	71.2	13.3	6.19	190	52
9	F	21	68.63	67.5	18.3	4.95	185	37
10	F	21	54.77	65.0	15.2	3.45	195	60
11	F	26	57.27	65.7	14.8	4.10	195	50
12	F	23	55.91	66.7	14.3	3.25	200	60
13	F	21	71.36	67.2	22.1	4.74	190	45
14	F	26	51.36	68.0	7.2	4.49	190	47
15	F	21	68.18	67.0	20.2	3.97	200	70

*Relatively high, yet consistent, values for maximum oxygen consumption were recorded for all subjects in the pre-test of this parameter.

Table 2
Exercise Intensity Study
 DESCRIPTIVE DATA
Control Group

Subject	Sex	Age	Weight kilograms	Height inches	% Body Fat	RestHR
1	M	21	68.5	67.0	8.3	40
2	M	23	75.9	71.5	7.2	45
3	M	24	70.9	72.2	6.8	52
4	M	22	75.3	72.0	12.5	56
5	M	29	71.8	71.5	10.2	47
6	M	20	87.0	74.4	18.2	60
7	F	23	62.7	70.5	12.8	50
8	F	22	57.3	68.0	8.2	56
9	F	29	64.5	67.5	22.3	55
10	F	22	66.4	65.0	12.2	52
11	F	20	55.9	67.0	10.5	50

*Maximum oxygen consumption($\dot{V}O_2\text{Max}$) and maximum heart rate(MaxHR) were not recorded for this group.

Table 3
Exercise Intensity Study
 EXPERIMENTAL GROUP
 25% Exercise Bout

Subject	Pretest		Immediate Posttest		3 Hour Posttest		6 Hour Posttest		24 Hour Posttest	
	*Cal	°C	*Cal	°C	*Cal	°C	*Cal	°C	*Cal	°C
	Diff	Kcal/Hour	Diff	Kcal/Hour	Diff	Kcal/Hour	Diff	Kcal/Hour	Diff	Kcal/Hour
1	3.55	64.8	5.33	119.8	6.60	161.8	5.70	129.9	3.40	63.8
2	3.82	76.1	5.20	117.2	5.60	130.2	4.67	102.2	4.80	104.2
3	4.10	85.1	4.40	91.1	4.00	77.1	4.20	85.1	3.40	62.1
4	4.15	85.1	4.68	101.2	4.69	103.2	5.03	109.2	5.90	137.1
5	6.00	143.8	3.32	57.8	4.00	79.8	4.10	80.2	5.60	129.8
6	5.23	115.4	5.35	118.4	5.30	119.8	4.05	74.4	5.10	112.4
7	4.80	103.9	5.65	131.9	5.80	135.9	5.80	135.9	4.80	103.9
8	4.66	101.5	5.00	108.4	4.48	94.4	3.70	70.4	4.70	102.4
9	5.20	115.0	5.20	117.1	5.20	115.1	4.80	105.1	5.80	135.1
10	3.40	60.4	5.00	108.4	4.90	106.4	4.40	90.4	3.94	76.4
11	4.20	85.5	3.50	62.5	3.40	61.4	5.20	114.5	5.00	110.5
12	4.55	94.5	4.82	104.4	3.80	72.5	4.20	85.4	4.37	90.5
13	3.40	59.1	5.35	127.4	4.20	86.4	4.00	79.4	4.80	103.4
14	2.86	44.6	5.30	122.2	5.50	124.6	3.80	72.6	4.24	84.6
15	4.82	105.0	4.20	91.0	4.40	91.2	3.80	74.0	5.10	117.0

*Cal °C Diff (Calorimeter °C Difference)

Table 4
Exercise Intensity Study
EXPERIMENTAL GROUP
75% Exercise Bout

Subject	Pretest		Immediate Posttest		3 Hour Posttest		6 Hour Posttest		24 Hour Posttest	
	*Cal	°C	*Cal	°C	*Cal	°C	*Cal	°C	*Cal	°C
1	4.40	92.8	4.35	89.8	4.10	82.8	3.58	64.8	3.30	57.8
2	4.66	101.2	4.36	91.2	4.26	90.2	4.00	89.2	4.90	111.2
3	4.41	93.1	4.80	105.1	5.70	133.4	4.72	102.1	5.40	123.1
4	6.06	147.2	6.22	152.2	5.50	126.2	6.60	162.1	4.80	105.2
5	4.45	94.8	4.80	105.8	5.50	126.2	5.30	119.2	5.20	123.8
6	4.22	86.4	5.97	143.4	4.85	106.4	3.60	66.4	5.35	120.4
7	4.20	86.9	5.20	123.9	5.56	123.9	4.60	95.9	5.44	125.9
8	4.40	91.4	5.98	144.9	3.40	61.3	3.90	75.4	4.05	76.4
9	4.30	89.1	5.00	109.1	2.60	35.1	3.30	57.1	4.20	92.1
10	4.60	97.4	5.00	108.4	3.20	60.4	3.36	60.4	3.10	53.4
11	3.10	54.5	4.20	85.5	4.64	99.5	5.20	120.0	3.30	56.5
12	2.10	22.4	3.70	71.4	3.94	77.4	3.10	51.4	4.93	108.4
13	4.26	86.4	4.98	108.4	5.20	122.4	4.30	87.4	4.70	100.4
14	5.40	121.6	5.40	122.6	4.00	77.6	4.30	87.6	3.50	62.4
15	4.30	88.0	5.00	109.0	4.44	93.0	3.20	71.0	3.90	77.0

Subject	Pretest		Immediate Posttest		3 Hour Posttest		6 Hour Posttest		24 Hour Posttest	
	*Cal °C	Kcal/Hour	Cal °C	Kcal/Hour	Cal °C	Kcal/Hour	Cal °C	Kcal/Hour	Cal °C	Kcal/Hour
1	5.10	114.1	5.10	114.1	5.14	119.1	3.30	57.1	3.40	61.1
2	6.50	162.1	6.50	162.1	6.63	162.3	4.30	89.3	4.90	108.3
3	3.60	67.1	3.60	67.1	3.60	67.1	4.55	95.1	4.60	98.1
4	3.20	55.3	3.20	55.3	3.40	62.3	3.40	62.3	3.90	77.3
5	4.10	86.1	4.10	86.1	3.90	77.1	3.60	66.1	3.70	71.1
6	4.25	95.8	4.25	95.8	4.45	94.8	3.30	57.8	3.60	68.8
7	4.70	102.8	4.70	102.8	5.25	122.8	4.82	104.8	5.30	118.8
8	2.40	28.5	2.40	28.5	3.60	66.5	4.50	95.5	2.50	31.5
9	3.90	78.9	3.90	78.9	4.10	81.9	4.30	88.9	4.30	88.9
10	2.95	44.5	2.95	44.5	3.00	46.5	3.20	53.5	3.40	54.5
11	3.20	60.5	3.20	60.5	3.20	60.5	3.80	72.5	3.70	70.5

*Cal °C (Calorimeter °C Difference)

Table 5
Exercise Intensity Group
CONTROL GROUP

from the Basal Tech Whole Body Calorimeter experiments for 25% and 75% of maximum oxygen consumption treatments for the Experimental group and the values derived for the Control group. Listed are the temperature differences between the internal environment of the calorimeter and the ambient air temperature in which the calorimeter is situated. Also listed in these tables are the derived kilocalories per hour values associated with the measured temperature differences. Kilocalorie values, or metabolic rates, are listed by assessment period:

- 1) pre-exercise resting metabolic rate,
 - 2) immediately post-exercise resting metabolic rate,
 - 3) three hours post-exercise resting metabolic rate,
 - 4) six hours post-exercise resting metabolic rate,
- and,
- 5) twenty-four hours post-exercise resting metabolic rate.

Metabolic rate values for the Experimental group are further divided by exercise intensity, 25% and 75% maximum oxygen consumption exercise bout treatments.

Table 6 and Figure 1 delineate the mean metabolic rates and standard deviations in kilocalories per hour for both the Experimental and Control groups, with both sexes included. As in the preceding tables metabolic rate values for the Experimental group are further subdivided by the exercise intensity treatment, 25% and 75% of

Table 6

Exercise Intensity Study

Whole Group Mean* Metabolic Rates(Kcal/Hour)
by Assessment Periods

	<u>Experimental Group</u> [®]		<u>Control Group</u>
	25% $\dot{V}O_2$ Max	75% $\dot{V}O_2$ Max	
1) Pre-exercise metabolic rate	88.77 (25.19 SD) [#]	89.56 (26.29 SD)	79.89 (35.40 SD)
2) Immediate post-exercise metabolic rate	105.24 (17.58 SD)	110.74 (21.19 SD)	79.89 (35.40 SD)
3) Three hours post-exercise metabolic rate	103.97 (26.50 SD)	94.39 (28.02 SD)	88.72 (32.96 SD)
4) Six hours post-exercise metabolic rate	88.59 (21.10 SD)	86.65 (28.58 SD)	72.49 (18.08 SD)
5) Twenty-four hours post-exercise metabolic rate	102.23 (22.59 SD)	88.42 (26.32 SD)	77.21 (23.91 SD)

*Group means are weighted to account for uneven groups.

[®]Experimental group values are listed for both 25 percent and 75 percent of maximum oxygen consumption tests.

[#]SD(Standard Deviation)

Figure 1: Whole Group Mean Metabolic Rates (Kcal/Hour:
Experimental Group (25% and 75%) and Control Group

maximum oxygen consumption exercise bouts.

Table 7 and Figure 2 identify mean metabolic rates, in kilocalories per hour, again for both the Experimental and Control groups with the two experimental treatment results treated separately. Table 7 and Figure 2, however, further subdivide the treatments and Control group values by sex, as well as group/treatment. Table 8 lists the percent and absolute changes in kilocalories from pre-exercise values.

The data for metabolic rate, in kilocalories per hour, for all subjects were submitted to analysis by a multivariate analysis of variance statistical computer program of the Statistical Package for the Social Sciences (SPSS). The purpose of this analysis was to identify any statistically significant effects of the main variables on metabolic rate. These main variables were the subjects' group and treatment within the group¹, sex, and time of assessment². In addition to the effects of the main

1. "group" encompasses the comparison of both Experimental group treatments, 25% and 75% of maximal oxygen consumption exercise bouts, as well as the Control group.

2. "time" refers to the five sequential metabolic rates assessed from the pre-exercise, immediate post-exercise, three hours post-exercise, six hours post-exercise, and 24 hours post-exercise assessment periods.

Table 7

Exercise Intensity Study

Mean* Metabolic Rates (Kcal/Hour) Divided by Sex
by Assessment Periods

	Experimental Group				Control Group [@]	
	25% $\dot{V}O_2$ Max		75% $\dot{V}O_2$ Max			
	Males	Females	Males	Females	Males	Females
1) Pre-exercise	96.96 (23.33)	80.58 (24.37)	99.22 (18.65)	79.91 (21.40)	96.74 (34.84)	63.04 (25.98) SD [#]
2) Immediate post-exercise	105.72 (23.24)	104.77 (20.56)	119.42 (23.41)	102.42 (16.08)	96.74 (34.84)	63.04 (25.98) SD
3) Three hours	112.77 (27.57)	93.91 (21.13)	106.31 (24.17)	80.76 (26.06)	97.12 (34.78)	74.24 (26.21) SD
4) Six hours	88.41 (25.49)	88.77 (14.42)	96.88 (30.12)	76.41 (22.14)	61.94 (17.82)	83.04 (18.15) SD
5) Twenty- four hours	101.96 (25.43)	102.50 (18.60)	98.25 (24.64)	78.60 (20.47)	80.78 (16.80)	73.64 (29.66) SD

*Group means are weighted to account for uneven groups.

[@]Since no exercise bout intervened with the Control Group, immediate post exercise resting metabolic rate was identical to pre-exercise values.

[#]SD (Standard Deviation)

Figure 2: Mean Metabolic Rates (Kcal/Hour) Divided By Sex By Assessment: Experimental Group (25% and 75%) and Control Group

Table 8

Kilocalorie and Percentage Increase in Metabolic Rate
Response to 25% and 75% Maximum Oxygen Consumption Exercise

	25%		75%		Control Group	
	Change in Kcal from pre-exer.	% of Change	Change in Kcal from pre-exer.	% of Change	Change in Kcal from pre-exer.	% of Change
Males						
Immed. Post-ex.	+8.76	+9.03%	+20.20	+20.35%	0	0
Three Hours	+15.81	+16.30%	+7.09	+7.14%	+4.38	+4.04%
Six Hours	-8.55	-8.81%	-2.34	-2.33%	-34.80	-35.97%
24 Hours	+5.00	+5.16%	-.98	-.97%	-15.96	-16.50%
Females						
Immed. Post-ex.	+24.19	+30.00%	+22.51	+25.17%	0	0
Three Hours	+13.33	+16.56%	+ .85	+1.06%	+11.20	+17.77%
Six Hours	+8.19	+10.16%	-3.50	-4.38%	+20.00	+31.72%
24 Hours	+21.92	+27.20%	-1.31	-1.64%	+10.60	+16.81%

variables on the subjects' metabolic rate these data were also analyzed for the interaction effects of:

- 1) the subjects' group and treatment within the group as divided by the sex of the subjects,
- 2) the subjects' group and treatment within the group as influenced by the time period of metabolic assessment,
- 3) the subjects' sex as affected by the time period of metabolic assessment,
- 4) the combined influence of the subjects' group and treatment within the group, sex, and time of metabolic assessment.

The multivariate analysis of variance procedure revealed the results listed in Table 9. The effects of the main variables can be seen from this table when the F-ratio $\alpha = .05$. That is, when:

$$1) F_{A, 3} = 4.59; df = 4/70; p < .002$$

the calculated F-value exceeds the tabled F-value of 2.53. Therefore, as a whole the results attained for the Control group and the 25% and 75% maximum oxygen consumption exercise bout treatments within the Experimental group differed significantly from one another. Reject the null hypothesis (H_0 !)

3. A = the subjects' specific group and treatment of the Experimental group

Table 9
Exercise Intensity Study
Multivariate Analysis of Variance

Sources of Variation	SS	df	Error SS	MS	Error MS	F	Significance of F	P(<.05)
Main Effects								
Group (A)*	130894.60	(4/70)	498571.81	32723.65	7122.45	4.59	.002	.002
Sex (B)	74345.72	(2/70)	498571.81	37172.86	7122.45	5.21	.008	.008
Time (C)@	479634.32	(4/140)	876057.38	119908.58	6257.55	19.16	.000	.001
Interaction Effects								
Group by Sex(AB)	20764.93	(4/70)	498571.81	5191.23	7122.45	.72	.575	NS
Group by Time(AC)	435595.71	(8/140)	876057.38	54449.46	6257.55	8.70	.000	.000
Sex by Time(BC)	80949.28	(4/140)	876057.38	20237.32	6257.55	3.23	.014	.014
Group by Sex and Time(ABC)	26877.17	(8/140)	876057.38	3359.64	6257.55	.53	.827	NS

*Group-the term "group" encompasses the comparison of both Experimental Group treatments, 25% and 75% VO₂Max exercise bouts, as well as, comparison of the Control Group.

@Time-the term "time" refers to the five sequential metabolic rates attained from the pre-exercise, immediate post-exercise, three hours post-exercise, six hours post-exercise, and twenty-four hours post-exercise resting metabolic rates.

$$2)F_B^3 = 5.21; df = 2/70; p < .008$$

The calculated F-value exceeds the tabled F-value of 3.15. Therefore, significant differences in metabolic rates existed between the male and female participants in the study. Reject the null hypothesis (Ho2:).

$$3)F_C^4 = 19.16; df = 4/140; p < .001$$

The calculated F-value exceeds the tabled F-value of 4.95. Therefore, significant differences in metabolic rate were found for all participants in the study as a whole from one metabolic assessment period to another. Reject the null hypothesis (Ho3:)

The interaction effects of the above three main variables when the F-ratio alpha = .05 are:

$$4)F_{AB} = .575; df = 4/70; p = n.s.$$

The calculated F-value does not exceed the tabled value of 5.13. Therefore, resting metabolic rate does not differ significantly between males and females for both the Control group and the two treatments of the Experimental group.

4. B = the subject's sex

5. C = the metabolic assessment period

$$5) F_{AC} = 8.70; df = 8/140; p < .001$$

The calculated F-value exceeds the tabled F-value of 3.55. Therefore, resting metabolic rate response differed significantly on a whole group basis between the Control group and the 25% and 75% of maximum oxygen consumption treatments of the Experimental group. Reject the null hypothesis (H_0 3:)

$$6) F_{ABC} = .537; df = 8/140; p = n.s.$$

The calculated F-value for differences between the Control group and the two treatments of the Experimental group, when viewed from the combined interaction effects of sex of the subjects and times of metabolic rate assessments, did not exceed the tabled value of 2.02. Therefore, significant group and treatment differences observed above for the individual effects of sex and time of metabolic assessment diminished when the two variables combined effects on group/treatment were considered.

Calorimeter Validation Study

Descriptive Data

Descriptive data for the five male subjects of the Calorimeter Validation study are included in Table 10. Each individual's sex, age, weight, height, predicted maximal oxygen consumption, and predicted maximal heart

Table 10

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CALORIMETER VALIDATION STUDY

Descriptive data

Sub- ject	Age	Height inches	Weight kg	Pre- dicted Max HR	Esti- mated VO ₂ Max	Rest./ Exer. HR	Pretest					Posttest				
							VE l/min.	VO ₂ l/min.	VC0 ₂ l/min.	RQ	Cal. Temp. Diff.	VE l/min.	VO ₂ l/min.	VC0 ₂ l/min.	RQ	Cal. Temp. Diff.
1	24	72.25	70.90	196	4.6	130/48	5.50	.323	.260	.80	4.60	9.38	.390	.328	.84	5.01
2	26	68.50	70.45	194	5.0	126/37	7.10	.325	.270	.83	4.00	7.11	.390	.299	.77	4.60
3	29	71.50	71.82	191	5.6	130/53	6.78	.256	.234	.91	3.70	8.23	.314	.237	.75	4.10
4	22	72.00	75.34	198	3.8	135/58	6.33	.285	.252	.88	4.00	9.00	.470	.378	.80	4.80
5	21	74.40	87.00	199	3.4	133/62	8.21	.312	.226	.72	3.70	9.81	.427	.328	.77	4.60

*Predicted HR 220-subject's age

@Estimated VO₂ Max is derived from the Astrand-
Rhyming Nomogram (see Appendix G) utilizing
the subject's submaximal pulse rate and workload.

rate are included in this table. This study sample was randomly selected from the same pool of volunteer males utilized in the Exercise Intensity Study. All subjects, therefore, met the identical criteria previously described for the parent population, including a twelve hour fast preceding the initial assessment of resting metabolic rate.

Experimental Data

Table 11 lists the pre-exercise and post-exercise resting metabolic rates for each male volunteer subject. Between the pretest and posttest of resting metabolic rate was an intervening bicycle ergometer exercise bout of fifty percent of predicted maximal oxygen consumption as determined by exercise heart rate. Preceding and subsequent to the twenty minute exercise bout resting metabolic rate, in kilocalories per hour, were determined utilizing simultaneous Basal Tech Whole Body Calorimeter and oxygen consumption assessment procedures.

Pearson product-moment correlation coefficients were derived for the metabolic rates, measured in kilocalories per hour, determined by the two assessment methods during the pre-exercise resting metabolic assessment period. This correlation coefficient was calculated to be .6207 with the mean calorimeter metabolic assessment method

Table 11
Calorimeter Validation Study
 EXPERIMENTAL DATA

Subject	Basal-tech Calorimeter Method	Oxygen Consumption Method
Pre-exercise Metabolic Rate		
1	97.15	93.16
2	78.12	94.28
3	69.18	75.89
4	77.10	83.77
5	69.75	88.02
	$\bar{x} = 78.26$	$\bar{x} = 87.02$
Post-exercise Metabolic Rate		
1	109.15	113.49
2	91.00	111.17
3	79.18	89.34
4	103.30	108.88
5	97.60	106.20
	$\bar{x} = 96.04$	$\bar{x} = 105.81$

Pretest: $r = .621$
 Posttest: $r = .829$

underestimating tabled values of metabolic rate(138) by almost eighteen kilocalories per hour. This means was calculated to be 78.26 kilocalories per hour. The mean oxygen consumption value(87.02 kilocalories per hour) also underestimated the tabled predicted value of metabolic rate by almost nine kilocalories per hour. The standard deviation of these pretest means are 10.13 and 6.72 kilocalories per hour respectively.

A Pearson product-moment correlation coefficient was utilized to compare the two assessment methods on post-exercise metabolic rate. The correlation coefficient is .829 with the mean calorimeter metabolic assessment method (96.04 kilocalories per hour) closely agreeing with the predicted table values for pre-exercise resting metabolic rate (96.00 kilocalories per hour). The oxygen consumption metabolic assessment method mean (105.81 kilocalories per hour) estimated over the tabled value for pre-exercise resting metabolic rate by almost ten kilocalories per hour. The standard deviations for the posttests of the two assessment methods were 10.36 and 8.58 kilocalories per hour respectively.

Finally, a multivariate analysis of variance statistical procedure was utilized to compare the pre- and post-exercise pairs of values of each subject's Basal Tech Calorimeter and oxygen consumption derived metabolic rates in kilocalories per hour. These data, located in Table

12 , reveal that significant differences exist between the metabolic rate values derived from the Basal Tech Calorimeter and the oxygen consumption method ($p < .04$), and between the pre- and post-exercise assessments of each measurement method ($p < .002$). However, there were no significant interactions between the effects of metabolic rate measurement and the pre- and post-exercise metabolic values ($p = .737$).

Table 12

CALORIMETER VALIDATION STUDY

Multivariate Analysis of Variance

Sources of Variance	Sum of Squares	df	Mean Square	F	Significance of F
F _A *	434.32	1	434.32	8.93	.04
Within Cells	194.55	4	48.64		
F _B **	1682.14	1	1682.14	50.20	.002
Within Cells	134.03	4	33.51		
F _{AB} ***	1.54	1	1.54	.1298	.737
Within Cells	47.60	4	11.90		

*A = Between methods of measurement of metabolic rate

**B = Between pre- and post-tests of both methods of measurement of metabolic rate

***AB = interaction effects of measurement method and test

DISCUSSION

The results of this study presented in the preceding chapter indicate that significant statistical differences existed between the Control group subjects and both the 25% and 75% of maximum oxygen consumption treatments of the Experimental group. That is, according to the results when all measures are considered as a whole, the group in which a subject was located as well as the intensity at which the subject exercised profoundly affected the metabolic rate profile of that individual. In addition, the results indicated that the metabolic rate response of all females in both groups was significantly different from the responses of all males in the study. Also, as was expected, metabolic rate was significantly affected by the time of measurement of that parameter. That is, although individual comparisons differ, when taken as a whole, pre-exercise, immediately post-exercise, three-hours post-exercise, six hours post-exercise, and twenty-four hour post-exercise resting metabolic rates differed significantly from one another when all subjects are considered.

The results also indicate two other important points about the subjects in this study. First, the Control

group and both treatments of the Experimental group resulted in significantly different metabolic rate response patterns from pre-exercise through twenty-four hour post-exercise resting metabolic rate assessment periods. Secondly, the metabolic rate patterns from pre-exercise through twenty-four hours post-exercise assessments differed significantly for males and females when both groups were analyzed as a whole. It is important at this point, however, to point out that sex differences were not important when analyzed in relation to the group and treatment and metabolic rate pattern of the subjects. That is, males and females in both groups and treatments seemed to respond similarly over the time of observation. These effects may most appropriately be explained in the light of the following analysis of the factors which contribute to metabolic rate response to exercise.

Phosphogens, Lactic Acid and Non-Oxidative Event Recovery ATP-PC System

It is well documented that the ATP-PC metabolic energy system is utilized in the initial phases of all exercise activity.(81) In both steady-state aerobic and non-steady-state anaerobic activity this initial phase of exercise is referred to as the alactacid component of the oxygen deficit period.(96) Owing to this energy system's

relatively small total muscular concentration of ATP-PC, 570-690 millimoles for the entire average man's muscle mass or on order of 19-23 millimoles of per kilogram of muscle, and to its relatively large maximal power capability of approximately 3.6 millimoles per minute, the ATP-PC system is exhausted in a relatively short period of time from the onset of exercise.(76,81,98) Karlsson (1971) indicates that no further decreases in the concentration of ATP-PC occurs after two to three minutes into activity. To be sure, according to Mathews and Fox (1981) the ATP-PC system is exhausted in those muscles utilized within ten to twenty seconds during maximally intense physical activity.

In studies conducted initially by Margaria, et al (1963), diPrampo and Margaria (1968), Pilper, et. al. (1968 and 1970) and latter supported by others(77,84) resynthesis of the ATP and PC utilized during the initial onset of exercise is, in major part, accomplished via energy derived from the oxygen system during the alactacid component of the oxygen debt period. The time of recovery of the ATP-PC system is directly related to the degree of depletion of this system during the exercise activity (101) Margaria, et al (1963) determined that depleted muscle phosphogen stores are completely resynthesized within thirty seconds to three minutes after exercise by way of the oxygen system. Indeed, the greater the

depletion of the ATP-PC stores in muscle the greater the oxygen required during recovery to replete these stores.(101) In studies conducted by Roberts and Morton(1978) and Hagerman, et al (1978), two to six liters of oxygen, depending on the severity of the exercise and level of training, as well as the phosphogen capacity of the athlete, have been recorded during the alactacid component of the oxygen debt period to restore the phosphogen stores depleted during the initial phases of exercise.

In light of this previous knowledge concerning the utilization and the restoration of muscle phosphogen stores during and after exercise, the current study is in general agreement. However, while the oxygen consumed and the metabolic heat initially recorded after each exercise bout in this study were higher values than those recorded in subsequent post-exercise assessments three, six and twenty-four hours later, it is unlikely that these initial values reflected restoration of the phosphogen stores. That is, the period of time necessary to transfer any given subject from the exercise treadmill apparatus to the post-exercise metabolic assessment site required approximately three to four minutes after exercise cessation. As indicated in the previous studies this duration of time is more than the time required to complete restoration of the phosphogen system. Also, as

might be expected, all other assessments of metabolic rate in this study would reflect the same shortcoming.

Lactic Acid System

A second component of the oxygen deficit period utilized in conjunction with the rapidly exhausting ATP-PC system and the still inadequately adjusted oxygen system is anaerobic glycolysis, or the lactic acid system.(8,71,73) From the onset of exercise until the oxygen system adjusts to the workload imposed upon it, assuming exercise to be submaximal steady-state in nature, anaerobic glycolysis supplements in an increasingly important manner the energy derived from the phosphogen system.(8,71,73) Likewise, in a decreasingly important manner, anaerobic glycolysis also supplements the energy supplied by way of the oxygen system.(8,39,90)

The potential power capability of anaerobic glycolysis is less than half that of the ATP-PC system. Hultman (1967) and Karlsson (1971) indicate that on average this system can supply only enough energy to synthesize approximately 1.6 millimoles of ATP per minute. However, the total capacity of anaerobic glycolysis to resynthesize ATP is almost twice that of the phosphogen system at approximately 1.2 moles. Contrarily, anaerobic glycolysis has a superior power capability and an inferior total capacity for the resynthesis of ATP to that of the

oxygen system.(76,81)

The end by-product which results from the utilization of anaerobic glycolysis for the resynthesis of ATP from the incomplete breakdown of cellular glucose is lactic acid. (24,53,68,75,76,81,91,133) According to Karlsson (1971), and echoed throughout the literature, this substance accumulates in the active muscle tissue and the blood during relatively long term anaerobic exercise. Complete recovery from lactic acid accumulation, therefore, requires the removal of lactic acid to basal levels in both areas of accumulation.(103) According to Brooks, Brauner, and Cassens (1973) and others (53,68,75) lactic acid is primarily metabolized to carbon dioxide, water and energy for ATP resynthesis by way of the enzyme systems of the oxygen system of skeletal muscle. In addition, the heart, liver, brain, and kidney also metabolize this substance in the presence of sufficient oxygen to permit such metabolism. (113,128,131,142) Additional, but less significant routes of lactic acid removal from muscle tissue and blood include removal via excretion in the urine and conversion to protein.(80)

According to Fox (1979), although the quantity of lactic acid removed during the lactacid component of oxygen debt following exercise cessation is related to the quantity of oxygen consumed during this same period, this relationship is inconsistent. He indicates that this

inconsistency is attributable to the interplay between the various routes of removal of lactic acid. Fox, Robinson, and Wiegman (1969) indicate that the total amount of oxygen consumed during the lactacid component of the oxygen period can vary from five to ten liters with the extent of oxygen consumption dependent upon the intensity of the activity performed. The removal of lactic acid from the blood and the skeletal muscle has been shown to be approximately ninety to ninety-five percent complete within one-hour and fifteen minutes after the cessation of exercise.(51,83)

In the current study, as indicated by the respiratory exchange ratios (R) recorded immediately post-exercise and throughout the immediate post-exercise period, removal of lactic acid was a primary function of the relatively large volumes of oxygen consumed per minute. Therefore, this study's results are in keeping with elevated R values found immediately post-exercise in previous studies of post-exercise metabolic rate. Indeed, the quantities of oxygen consumed in subsequent metabolic rate assessments of each exercise bout in this study were not characterized by the large oxygen consumption values of the immediate post-exercise period.

Additionally, in the current study, the highest mean metabolic heat values were anticipated to be recorded immediately post-exercise period. This, indeed, was the

pattern for Experimental group males and females following the 75% of maximum oxygen consumption treatment and for Experimental group females following the 25% of maximal oxygen consumption treatment. The highest mean temperatures recorded for Experimental group males following the 25% of maximal oxygen consumption treatment occurred at the three hours post-exercise assessment period however. This is indicated in Figure 2 of the Results chapter. Owing to the relatively large oxygen deficit period of the 75% of oxygen consumption exercise bout relatively larger accumulations of lactic acid could be expected to accumulate during this pre-steady state period than would occur in the less intense exercise bout. In addition, owing to the greater energy requirements of the more intense exercise bout during the exercise period greater heat accumulation would reasonably be expected to be carried into the calorimeter immediately post-exercise.

Less profound increases in immediate post-exercise metabolic heat were recorded in males after the 25% of maximal oxygen consumption exercise bout than was expected, while the immediate female response followed the temperature pattern of that of the more intense exercise bout. The male response in this less intense treatment was to record highest metabolic rate then decline to below pre-exercise resting values by the sixth hour post-exercise. This pattern may reflect a decreased

lactic acid accumulation in the Experimental group males at the less intense work load and the influence of other factors, including the elevation of thyroid hormones, following exercise.

Non-Oxidative Events Post-Exercise

In addition to those oxygen requiring events of the alactacid and lactacid components of the oxygen debt period other oxidative and non-oxidative events effect the quantity of oxygen consumed and metabolic heat generated during the post-exercise period. The first of these events to be considred is the resynthesis of muscular stores of glycogen. Following exercise which significantly depletes muscle glycogen stores the full repletion of these stores requires two to five days after exercise performance.(35,78) According to Hultman and Bergstrom (1967) and Costill, et al. (1971) and others (69,94) the rate of glycogen resynthesis is closely dependent upon the quantity of dietary carbohydrate consumed during the recovery period and the type exercise employed to deplete the muscular glycogen stores. Indeed, according to studies conducted by MacDougall, et al. (1977) and Hermansen and Vaage (1977), significant glycogen repletion has been demonstrated to occur following exhausting intermittent work followed by either a normal mixed diet or one high in carbohydrates. The

energy required for the resynthesis of glycogen from 73
lactic acid and dietary sources of carbohydrates is
derived from the oxygen system.(102)

In the present study, although unmeasured, the
resynthesis of glycogen represents a potential source of
oxygen consumption and metabolic heat production for an
undetermined time period post-exercise. Indeed, the
degree of skeletal muscle glycogen utilization is
exercise intensity, as well as duration,
dependent.(78,119) It seems likely, therefore, that the
differences in oxygen consumed and the metabolic heat
produced after the treadmill running exercise at 25% and
75% of maximal oxygen consumption is at least in small
part explained by the differences in the extent of
glycogen repletion.

Another factor to contribute to the post-exercise
oxygen debt period is restoration of the oxygen-myoglobin
stores of skeletal muscle. The contribution of this
factor is somewhat limited in effect and duration,
however, due to the relatively small stores of oxygen in
myoglobin, 336 to 500 milliliters, in the average man and
the rapid time of recovery, approximately one to two
minutes.(65) Still other small increases in oxygen
consumption post-exercise which may contribute to the
short run elevation in metabolic rate are the restoration
of oxyhemoglobin levels to resting levels and the

replenishment of oxygen dissolved in tissue fluids.⁷⁴(40)
However, again the contribution of these elements are small in magnitude and duration of effect and seem only to have effect on metabolism and oxygen consumption immediately post-exercise in the present study.

Two factors related to increased oxygen utilization which seem to offer a longer term explanation of the observed elevation in metabolic rate as well as oxygen consumption post-exercise in this study are: 1) the sustained elevated oxygen requirements of cardiac and pulmonary muscles which remain active long after the cessation of exercise (30,70) and, 2) an increase in oxygen consumption related to a general whole-body increase in tissue temperature which results from exercise.(25,26,27)

Hormonal Influence on Post-Exercise Metabolic Rate

During exercise performance changes occur in the blood's concentration of some hormones and substrates.(23)

These changes include gains and losses in the concentration in the blood of these substances. In addition, a return to pre-exercise levels of the hormones may or may not immediately occur upon cessation of exercise performance.(123) Indeed, two classes of hormones which have both short term and long term influence on metabolic rate and subsequent kilocalorie

expenditure are the thyroid hormones and the catecholamines. (37,49,54,59,62,117,123,135,139) These hormones jointly express an immediate effect on metabolic rate as well as an affect that persists for many hours and days after exercise.

Thyroxine, Triiodothyronine, and Thyroid Stimulating Hormone

According to Guyton (1981), the hormones secreted by the thyroid gland, thyroxine and triiodothyronine, are well known to have an important effect on cellular metabolic rate, oxygen consumption and subsequent production of metabolic heat. Thyroid hormone mediated metabolic rate has been recorded to range from sixty to one-hundred percent above resting normal values.(59) The effect on metabolic rate of triiodothyronine has been demonstrated to be approximately four times as rapid as that of thyroxine with the duration of effect on metabolism of the latter hormone approximately four times as long as the former.(59)

During exercise both thyroxine and triiodothyronine are taken up by the active muscle tissue at a more rapid rate than normally occurs at rest.(123) As indicated by Refsum and Stromme (1979), the net effect of exercise induced increases in hormone uptake is to reduce their concentrations in the blood, which subsequently stimulates the further release of these hormones from the thyroid

gland.

In an apparent feedback response to the anterior pituitary and hypothalamus glands thyroid-stimulating-hormone is released when blood concentrations of the two thyroid hormones are reduced.(54,59,123) This reduction in their concentration subsequently results in an increase in thyroxine and triiodothyronine release from the thyroid gland.

A study by Refsum and Stromme (1979) of the effects of prolonged submaximal snow skiing exercise, lasting a duration of five to over seven hours, revealed an elevation in thyroxine and triiodothyronine during exercise performance. It is proposed that this elevation in the blood's concentration of these two hormones may have resulted from a rapid increase in thyroid-stimulating-hormone during exercise.(109) Subsequent to the exercise bout in the Refsum and Stromme study, however, the concentrations of both hormones dropped to below pre-exercise concentrations in the blood and recovered only slowly over the subsequent four days. The results of this study seemed to indicate a rapid uptake of thyroxine and triiodothyronine by active tissue both during and after exercise, and a simultaneous inability of the thyroid gland to cope with the increased cellular demands for these hormones. Concurrent to the above events in the blood, the concentration of

thyroid-stimulating-hormone nearly doubled its concentration during the exercise period and remained elevated for up to four days post-exercise.(123)

In a related study, Terjung and Tipton (1971) found no change in the blood concentrations of thyroid-stimulating-hormone during the performance of submaximal work and up to twenty-four hours post-exercise. The results of this latter study suggests that a possible threshold of exercise intensity is required for a change in this hormone's concentration.(109) Indeed, the above evidence concerning the nature of the thyroid hormones response to exercise seems to coincide closely with the measurements of metabolic rate obtained in the current and previous studies of the effects of exercise intensity and duration on metabolic rate post-exercise. (16,17,18,19,20,21,41,70,79,141,143) That is, post-exercise metabolic rate and the duration of time over which it persists seems to be a function the duration and the degree of intensity of exercise.

The mean metabolic response of male Experimental group subjects to the 25% of maximum oxygen consumption exercise bout, while possibly representing investigator or instrument error, may indeed be a response to elevated thyroid and thyroid stimulation hormonal levels. This, however, does not explain the decline in metabolic rate pattern displayed by the males and females to the 75% of

maximum oxygen consumption exercise bout and females metabolic rate response pattern to the less intense exercise bout. It is interesting to note that the mean reduction in metabolic rate for the 25% of maximum oxygen consumption treatment for females from the three to six hour assessment periods was less pronounced (10.86 kilocalories per hour) than for both the male and female subjects during the more intense treatment. The respective mean reduction in female and male metabolic rate during the three to six hour post-exercise period of the 75% of oxygen consumption treatment was 13.11 and 20.66 kilocalories per hour. Finally, it is important to point out that the standard deviation of male subjects of the less intense treatment was 27.57 kilocalories per hour, indicating that a less uniform increase in metabolic rate from three to six hours post-exercise was observed in this group. It is the opinion of the investigator that subsequent investigations of the effects of exercise intensity and duration on post-exercise metabolic rate include a simultaneous assessment of blood concentrations of thyroid hormones.

Catacholamines

The primary manner in which the catacholamines hormones effect cellular metabolic rate is through the transmission of nervous stimuli from the sympathetic and parasympathic nervous systems to the effector cells and

organs.(59) These substances bind with receptors on the effector cells and through altering the cell receptor the neurotransmitter changes the permeability of the cell to sodium, potassium, chloride and calcium. This change in permeability ultimately leads to depolarization of the effector cell and the promotion of various electrolyte dependent functions of the cell.(59) These cellular functions include the metabolic energy utilizing process of muscle fiber stimulation and contraction in skeletal muscle cells.(59,62,117,139) Indeed, physical exercise working alone or in conjunction with cold, emotional stress, body posture, circadian rhythm or a number of other factors can elevate the plasma level of plasma concentrations of epinephrine and norepinephrine (48,52,89,134) Therefore, the sustained presence of the catacholamines in the synaptic clefts and the circulating blood is indicative of continued parasympathetic and sympathetic nervous stimulus to the effector cells with a comcommitant elevation of metabolic energy.

The life expectancy the catacholamines in the blood is a few up to thirty seconds.(59) This would indicate a short run effect of these agents on metabolic rate. Therefore, the continued presence of these substances in the circulating blood suggests sustained nervous stimulation to the effector cells. Consequently, a sustained elevation of serum catacholamines reflect not

only the degree of stimulus to the effector cells and subsequent elevation of metabolic rate but also the degree to which the autonomic nervous system perceives stress to the organism and subsequently contributes to metabolic rate.(9,59)

Elevated blood concentration levels of catecholamines occur during exercise and contribute to the immediate elevation of metabolic rate of effected tissue.(13,48,110)

The elevation in blood catecholamines is related to the intensity of exercise with the concentration of these substances increasing with increased intensity of exercise.(37,49,54,62,117,139) Bannister and Griffiths (1972) indicate that the concentration levels of catecholamines increase with the both the duration as well as with the severity of muscular exertion.

The effect of norepinephrine and epinephrine is particularly important in in liberating large quantities of uncoupled energy in brown fat tissue which results in large metabolic heat production but little resynthesis of ATP.(60) A study by Winder, et. al. (1978) found that catecholamine response to submaximal exercise diminished with training over a period of days which suggests reduced stimulation from the sympathetic parasympathetic nervous systems as a result of training. In the current study the effect of blood catecholamine concentrations as induced by various degrees of exercise intensity seems an important

potential contributor to the degree and duration of observed differences in metabolic rate. However, since in the present study this variable was not determined, the extent of catecholamines concentration and uptake on these results is an unquantified mystery. Indeed, the effects catecholamines on metabolic response during exercise and exercise training, as well as daily work stress, would seem to a profitable avenue to pursue in further investigation of the effects of exercise intensity and duration on post-exercise metabolic rate.

Metabolic Cycles

Circadian Rhythms

For all male and female subjects the effects of daily fluctuations, circadian rhythms, of a variety of physiological functions such as heart rate, rectal temperature, urinary excretion of potassium, catecholamine levels, and oxygen consumption indicate significant regular alterations in the level of resting metabolic rate(10) In terms of metabolic rate, the lowest values are commonly recorded in the early morning hours between 3 a.m. and 5 a.m. and rising to a peak rate in the afternoon hours.(10)

The circadian changes in metabolic processes have been observed to be associated with changes in physical performance with the lowest performances observed in the

morning hours (127) While it is common for individuals to follow this low to high metabolic pattern it is also common to find other metabolic patterns.(66) To be sure, according to Hauri (1980) "morning" and "night" people seem to follow different metabolic patterns.

Consideration, therefore, must be given to the effects of time of day measurement values observed of resting and exercise metabolic rates. In the current study, while the times of assessment of metabolic rate varied for each individual subject according to their availability, measurement of metabolic rate at twenty-four hours was consistent with the time of initial pretest. In addition, for comparative purposes the times of day associated with metabolic assessments in the 75% of maximal oxygen consumption test were held consistent with the times previously associated with the 25% test.

Metabolic rate observed in the Control group and in the two treatments of the Experimental group from three to six hours and from six hours to twenty-four hours post-exercise seem to reflect a strong influence of circadian rhythm. The effect of exercise intensity seems to be to reduce the degree of metabolic rate decline which would normally occur in a daily cycle and maintain relatively elevated metabolic rate levels after the less intense exercise bout for both males and females, while the more intense exercise bout did not provide for the

same elevation for females.

Effects of the Female Sexual Cycle

In addition to the effects of daily circadian rhythms the metabolic rate of females reflect to a small extent the effects of their individual cyclic phase in their female sexual (or menstrual) cycle. This cycle, and its resultant influence on the female metabolic rate is controlled by the cyclic secretion of the gonadatropic and ovarian hormones with beta-estradiol exerting the greatest direct potential influence.(61) Despite substantial monthly cyclic increases in estrogen levels, metabolic rate rises only a small percentage and has not been found to be significantly affected by the phase of the sexual cycle.(61) Indeed, it is the consensus of opinion that no systematic metabolic or cardiovascular responses occur at rest or during exercise as a result of the phase of the female menstrual cycle.(3,61,106) Apparently, therefore, any perceived changes in metabolic rate or perceived exertion while exercising during the various phases of the female sexual cycle are subjective in nature and may be more or less pronounced during a particular sexual phase.(55)

In the present study the female subjects displayed a scattered distribution across the female sexual cycle, with one subject currently ammenorrheic. The effect of the female sexual cycle in this study on metabolic rate was

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consistent with previously reported studies. That is, in this study the phase of the female sexual cycle did not significantly influence exercise, pre- and post-exercise metabolic responses. The Pearson product-moment correlation coefficient of the day of menstration onset in females to pre-exercise and post-exercise metabolic rate was .51 and .38 respectively for the 25% and 75% maximum oxygen consumption exercise treatments.

Male/Female Metabolic Differences

As reflected in the pretest, exercise, and various posttest assessments of metabolic rate the female subjects of this study as a group did exhibit a significantly lower metabolic rate and absolute utilization of caloric energy per unit of time than did the male subjects of this study. These results are consistent with previous findings which indicate that maximal oxygen consumption in females is fifteen to twenty-five percent less than those observed in males.(105) Therefore, the absolute maximal ability of females to consume energy per unit of time is less than that of males. However, despite the obvious metabolic parity in absolute terms these male/female differences in maximal oxygen consumption and caloric use are reduced when caloric expenditure is expressed relative to total body weight.(105)

To be sure, the greater absolute size of the active muscle mass in males is, in large part, responsible for

the greater absolute metabolic values observed. Indeed,⁸⁵ the relatively greater hormonally mediated fat deposit of females is considered and if oxygen consumption and metabolic rate are expressed relative to lean body mass, the differences in metabolic rate between males and females become minimal. (36,38,44,105) In large measure, therefore, the differences observed between male and female metabolic rates are a function of the relatively greater proportion of body fat in the female body composition relative to that of the male.

Calorimeter Validation Study

The results of the Calorimeter Validation study indicate that the pre-exercise measure of resting metabolic rate was underestimated by the Basal Tech Whole Body Calorimeter when compared to the oxygen consumption method and the tabled values. The Pearson product-moment correlation of oxygen consumption to the calorimeter was only .6207. According to Webb(1981), direct measures of energy expenditure have been known to correlate more highly with oxygen consumption. This correlation may have been stronger if expired air had not been simultaneously collected in a collection bag outside the internal environment of the calorimeter as heat loss certainly accompanied expirations. The r value for the posttest

measure of metabolic rate was higher, .829, however, the⁶⁶ calorimeter still underestimated the oxygen consumption values of post-exercise metabolic rate. The calorimeter assessment method agreed identically with the pre-exercise resting values (96.00 kilocalories per hour), but was on average almost ten kilocalories below post-exercise oxygen consumption of metabolic rate.

In this study, external temperatures of the Basal Tech Whole Body Calorimeter were subject to up and down fluctuations of air temperature control devices. It is postulated that the accuracy of the Basal Tech Whole Body Calorimeter measurement of metabolic rate could be increased by maintaining constant external temperatures. An undetermined degree of inaccuracy occurred in the instantaneous readings obtained from the calorimeter. This was due to undetermined lag time in the response of the calorimeter temperature adjustment to changes in the external temperature.

CONCLUSIONS

The following was concluded about this study:

1) Immediate post-exercise metabolic rate in males elevated with increased exercise intensity,

2) Post-exercise metabolic rate in females did not differ significantly with change in exercise intensity,

3) The degree of change in metabolic rate from immediate post-exercise to six hours post-exercise is different in males and females with;

a) males exhibiting higher absolute immediate post-exercise temperature at both 25% and 75% treatments and,

b) males, after the 75% treatment, exhibiting a gradual decline in metabolic rate to six hours when pre-exercise values were established,

c) alternatively, males, after the 25% treatment climbed gradually to three hours and declined sharply to below pre-exercise levels,

d) females, after the 75% treatment declined in metabolic rate at a nearly corresponding pattern to similarly treated males,

e) after the 25% treatment, females declined at a slower rate than after the more intense treatment, never

returning to pre-exercise levels.

In keeping with the results of this study, it is proposed that variations in exercise intensity may be used to elevate metabolic rate as a strategy for body weight control. It is suggested that two or more twenty minute exercise bouts, six hours apart, at either 25% or 75% of maximum oxygen consumption intensities be utilized by males to maintain elevated metabolic rate. This strategy, however, would be modified for females based on the intensity of exercise. For females, a 25% work bout is sufficient to maintain elevated metabolic rate for a sustained period post-exercise. This, however, needs further verification by research.

SUMMARY

The effects of exercise intensity on metabolic rate during exercise have been well documented. Substantial research has established well the effects of exercise on phosphogen depletion, lactic acid accumulation, and glycogen depletion. Indeed, the effects of these substances on the immediate post-exercise oxygen debt period metabolic rate are well known to be responsible for continued high oxygen consumption levels after the cessation of exercise. Studies, however, indicate that metabolic rate is maintained for varying periods post-exercise unrelated to immediate oxygen debt period with resultant additional kilocalorie use.

The specific effects of exercise duration and intensity on post-exercise metabolic rate remains unquantified, however. The purposes of this study, therefore, were to assess the effects of two exercise intensities, 25% and 75% maximum oxygen consumption of equal twenty minute durations on :

- 1) the degree of elevation in post-exercise metabolic rates, and
- 2) the time period over which the change in metabolic rate persists in males and females.

In this study, eight males and seven females, college

age, were preassessed for maximum oxygen consumption while exercising on a treadmill. Heart rate was titrated with oxygen consumption and utilized to establish 25% and 75% of maximum oxygen consumption workloads for each subject. Subsequently, each subject, on two separate occasions, at least five days apart, was assessed after a twelve hour fast for:

- 1) resting metabolic rate utilizing a Basal Tech Whole Body Calorimeter over a twenty minute period, then
- 2) exercised on a treadmill over a twenty minute period at either 25% or 75% maximum oxygen consumption, then assessed for post-exercise metabolic rate on four sequential occasions for twenty minutes each time. These sequential time periods were: a) immediately post-exercise, b) three hours post-exercise, c) six hours post-exercise, and d) twenty-four hours post-exercise. A six male, five female non-exercising Control group was assessed on the same parameters during the same time periods as the Experimental group.

The results of this study indicate, first, significant differences post-exercise for the combined male-female Control group and 25% and 75% treatments of the Experimental group, $P < .002$. Secondly, between the two treatments of the Experimental group and the Control group, metabolic rate varied significantly by assessment period, $P < .001$. Third, the metabolic rate response of females, considered as a whole,

was significantly different from that of males to exercise, $P < .008$. However, considering metabolic rate as a product of the group or treatment and sex of the subject, no significant difference in metabolic rate was observed over the whole time of measurement, $p = ns$. Indeed, the post-exercise metabolic rate varied with the intensity of exercise and it varied with the sex of the subject. However, the duration of effect on metabolic rate of exercise intensity was not different between treatments.

A separate study of the Basal Tech Whole Body Calorimeter, with five male subjects from the same pool of subjects used in the Exercise Intensity Study, was conducted to validate the metabolic measurements derived from this instrument against those measurements derived from oxygen consumption assessment. In this study, the subjects were assessed for pre-exercise metabolic rate lying supine in the Basal Tech Whole Body Calorimeter while simultaneously expired volumes of air were collected in bags outside the instrument through a tube exiting the instrument. Subjects subsequently exercised on a bicycle ergometer at a predicted 50% of maximum oxygen consumption for twenty minutes. Subjects were immediately assessed for post-exercise metabolic rate utilizing, once again, the Basal Tech Whole Body Calorimeter and oxygen consumption methods. The data was then subjected to a Pearson product moment correlation coefficient statistical procedure to determine the

relationship of the pre-exercise and post-exercise metabolic rate values. The r for the pre-exercise metabolic rate values was .621 with the Basal Tech Whole Body Calorimeter underestimating the oxygen consumption method by nearly 18 kilocalories. The post-exercise metabolic rate r was .829 with the Basal Tech Whole Body Calorimeter method underestimating oxygen consumption by nearly 19 kilocalories.

APPENDIXES

APPENDIX A

APPENDIX A

Figure 5: Basal Tech Whole Body Calorimeter

APPENDIX A

Figure 1: Calorimeter temperature-calories conversion chart

APPENDIX A

Figure 2: Calorimeter body weight - calories correction chart

APPENDIX A

Calculation Procedure

1. Enter Figure 1 to obtain $Q_3, \frac{\text{Cal}}{\text{hr}}$, basal heat _____
2. Enter Figure 2 to obtain $Q_v, \frac{\text{Cal}}{\text{hr}}$, evaporative heat _____
3. Add results of steps 1 and 2, to obtain $Q_{3v}, \frac{\text{Cal}}{\text{hr}}$, body heat

$$Q_{3v} = Q_3 + Q_v, \frac{\text{Cal}}{\text{hr}} \quad \underline{\hspace{2cm}}$$

4. Calculate daily body heat, $\frac{\text{Cal}}{\text{day}} = \text{DCN}_1$

$$\text{DCN}_1 = Q_{3v} \times 24, \frac{\text{Cal}}{\text{day}} \quad \underline{\hspace{2cm}}$$

5. Calculate daily physical activity increment, $\frac{\text{Cal}}{\text{day}} = \text{DCN}_2$

$$\text{DCN}_2 = \underline{\hspace{2cm}}, \text{ obtained from Table I} \quad \underline{\hspace{2cm}}$$

6. Calculate Daily Caloric Needs, $\text{DCN}, \frac{\text{Cal}}{\text{day}}$

$$\text{DCN} = \text{DCN}_1 + \text{DCN}_2 \quad \underline{\hspace{2cm}}$$

7. Calculate the Basal Metabolic Rate, $\text{BMR}, \frac{\text{Cal}}{\text{kg hr}}$

$$\text{BMR} = Q_{3v}, \frac{\text{Cal}}{\text{hr}} / \text{Body weight, kg} \quad \underline{\hspace{2cm}}$$

Figure 3: Calorimeter Calculation Procedure

APPENDIX A

DATA TABLE

Date _____ Location _____

Operator _____

I. Subject _____ Home _____ Zip _____

Name _____ Address: Work _____ Zip _____

Telephone No. Home _____

Work _____

Weight _____/lb _____/kg Height _____/in _____cm Birthdate ____/____/____ Age ____ years

General Diet _____

Weight Stable _____

Tested For Thyroid _____

II. Basal Metabolic Rate (BMR)

Time, min	Outlet Temperature T ^o C	Room Temperature (t _o) °C	$(T-t_o) \times 1$
0*			
5			
10			
15			
20			
25			
30			
35			
40			
45			
50			
55			

(T-t_o)_{av} = _____

*before the subject is in the calorimeter

III. Physical Activity During a Typical Day

Activity	Duration, hr**	Activity	Duration, hr**
Sleep		Standing	
Sitting		Driving a car	
Eating		Walking	
Work (describe)		Exercise (describe)	
Leisure (describe)		Other (describe)	

** total equals 24 hours

Figure 4: Calorimeter data collection table

APPENDIX B

APPENDIX B

Modified Basal Tech Whole Body Calorimeter

APPENDIX C

APPENDIX C

Astrand - Rhyming Nomogram

APPENDIX D

APPENDIX D

As previously described in Chapter 3, Section D-5, the Basal Tech Whole Body Calorimeter is a seven by three by three foot rectangular box designed for the purpose of measuring changes in heat in its internal environment when a steady stream of air is passed through it. Figure A-1 depicts the Basal Tech Whole Body Calorimeter design.

Reprinted with the permission of Daniel Hershey from the text, A New Age-Scale For Humans, the following outlines the theoretical and operational principles of the Basal Tech Whole Body Calorimeter

Thermal Analysis of the Calorimeter

Calibration Data

The basic transport equation governing the exchange of energy for the whole-body calorimeter (figure 7-1) is

$$\left\{ \begin{array}{c} \text{rate of} \\ \text{energy} \\ \text{in} \end{array} \right\} - \left\{ \begin{array}{c} \text{rate of} \\ \text{energy} \\ \text{out} \end{array} \right\} + \left\{ \begin{array}{c} \text{rate of} \\ \text{energy} \\ \text{generation} \end{array} \right\} - \left\{ \begin{array}{c} \text{rate of} \\ \text{energy} \\ \text{depletion} \end{array} \right\} = \left\{ \begin{array}{c} \text{rate of} \\ \text{energy} \\ \text{accumulation} \end{array} \right\}$$

With the notation in figure 7-4, and using these definitions

Q_1 = enthalpy of the inlet airstream, cal/hr
 Q_2 = enthalpy of the outlet airstream, cal/hr
 Q_3 = heat generated by a heating mantle (used for calibration of the calorimeter), cal/hr
 Q_4 = heat loss from the whole-body calorimeter, cal/hr

we get
$$Q_1 - Q_2 + Q_3 - Q_4 = \frac{\partial U}{\partial t} \quad (7.2)$$

where

U = internal energy of the whole-body calorimeter

Equation 7.2 can be rewritten as

$$\dot{m}_1 C_{p1}(T_1 - T_0) - \dot{m}_2 C_{p2}(T - T_0) + Q_3 - (hA + kA/\Delta X)(T - T_0) = (\rho_i V_i C_{vi} + \rho_w V_w C_{vw} + \rho_m V_m C_{vm}) \frac{\partial T}{\partial t} \quad (7.3)$$

where

$\dot{m}_1$ = inlet dry air mass flow rate
 $\dot{m}_2$ = outlet dry air mass flow rate
 C_{p1} = heat capacity at constant pressure of the inlet airstream
 C_{p2} = heat capacity at constant pressure of the outlet airstream
 T_1 = inlet airstream temperature
 T_0 = ambient temperature surrounding the calorimeter

Figure 7-4. Thermal Analysis of the Whole-Body Calorimeter when a Human Subject is lying inside it

T = outlet airstream temperature
 q_i = density of the air inside the calorimeter
 q_w = density of the wall material of the calorimeter
 V_i = inside volume of the calorimeter
 V_w = volume of the wall material of the calorimeter
 V_m = volume of the heating mantle inside the calorimeter (where it is used in the calibration studies)
 C_{vi} = heat capacity at constant volume of the air inside the calorimeter
 C_{vw} = heat capacity at constant volume of the calorimeter wall material
 C_{vm} = heat capacity at constant volume of the heating mantle inside the calorimeter
 k = thermal conductivity of the calorimeter wall material
 h = convective heat transfer coefficient for heat loss from the calorimeter to its surroundings
 A = calorimeter area for heat loss by conduction and convection
 ΔX = wall thickness of the calorimeter

Because the temperature rise of the airstream from inlet to outlet is only a few degrees (Fahrenheit), we can assume

$$\dot{m}_1 C_{p1} \cong \dot{m}_2 C_{p2} \cong \dot{m} C_p \quad (7.4)$$

Let us define α , β , and γ as follows:

$$\alpha = hA + kA/\Delta X \quad (7.5)$$

= first calibration constant for the calorimeter

$$\beta = q_i V_i C_{vi} + q_w V_w C_{vw} + q_m V_m C_{vm} \quad (7.6)$$

= second calibration constant for the calorimeter

$$\gamma = \dot{m} C_p \quad (7.7)$$

Substituting equations 7.5 through 7.7 into equation 7.3, we obtain

or

$$\gamma(T_1 - T) - \alpha(T - T_0) = \beta dT/dt$$

$$dT/dt + \left(\frac{\alpha + \gamma}{\beta}\right)T = (\alpha T_0 + \gamma T_1 + Q_3)/\beta \quad (7.8)$$

Let

$$P = \frac{\alpha + \gamma}{\beta} \quad (7.9)$$

$$W = (\alpha T_0 + \gamma T_1 + Q_3)/\beta \quad (7.10)$$

Substituting equations 7.9 and 7.10 into equation 7.8, we can get

$$dT/dt + PT = W \quad (7.11)$$

Equation 7.11 can be solved with its initial condition

$$\text{IC } T=T_0 \text{ at } t=0 \quad (7.12)$$

to obtain

$$T(t) = (T_0 - W/P) \exp(-Pt) + W/P \quad (7.13)$$

For long times, $t \rightarrow \infty$. we get from equation 7.13

$$T_\infty = W/P \quad (7.14)$$

where T_∞ represents the temperature of the outlet airstream at steady state and constant Q_3 .

Substituting equation 7.14 into 7.13 and with some rearrangement, we get

$$\ln(T_\infty - T) = \ln(W/P - T_0) - Pt \quad (7.15)$$

During the calibration experiment, T_0 , T_1 , T_∞ , and Q_3 are measured as a function of time, t . From the slope of the plot of $\ln(T_\infty - T)$ versus t , that is, $-P$, P can be calculated. Thus with known P and T_∞ , from equation 7.14 W can be obtained. Gamma can be calculated from our experimental conditions as shown below:

Let

$$\begin{aligned} \dot{m} &= \dot{m}_1 = \dot{m}_2 \\ &= (35 \text{ l/min})(60 \text{ min/hr})(1/28.32 \text{ ft}^3/\text{l})(0.074 \text{ lb m/ft}^3) \\ &= 5.487 \text{ lb m/hr dry air} \end{aligned} \quad (7.16)$$

then

$$\begin{aligned} \gamma &= \dot{m}C_p = (5.487 \text{ lb m/hr})(0.25 \text{ Btu/lb m}^\circ\text{F}) \\ &= 1.37 \text{ Btu/hr}^\circ\text{F} \end{aligned}$$

With known γ , Q_3 , P , and W , equations 7.9 and 7.10 can be rearranged to give

$$(7.17)$$

$$\beta = (-\gamma T_0 + \gamma T_1 + Q_3)/(W - P T_0) \quad (7.18)$$

$$\alpha = P\beta - \gamma \quad (7.19)$$

and thus we can determine α and β , that is, the two calibration constants required during the experiments with human subjects. Thus equations 7.18 and 7.19 are the working equations for the calibration experiments.

During the calibration experiments, we put a heating mantle in the calorimeter. The heating mantle was connected to an adjustable powerstat and wattmeter. With fixed $\dot{m}$ and γ , for constant Q_3 (adjusted by the powerstat and wattmeter), we measured T_0 , T_1 , and T at 5-minute intervals for the first hour. Then additional data were obtained every hour for the next 5 hours.

From equations 7.14, 7.15, 7.18, and 7.19 and with our original data, we can get P , W , and the two calibration constants α and β . In appendix C, we present one sample calculation of P , W , α , and β from calibration experiment data. The results of fifteen calibration runs are summarized in table 7-1.

The calibration curve for the SKAN-FLO flowmeter (tube number 1/4-36-6-7; float number Bj-8; SCH 74-62328) used to measure the airflow rate into the whole-body calorimeter is shown in figure 7-5.

Basal Metabolic Rate Measurement of a Human Subject

During the human subject experiments, T_0 , T_1 , and

$T(t)$ are measured. Using the experimental data and equation 7.13, the slope of the plot of $T(t)$

Table 7-1
Calibration Constants for the Whole-Body Calorimeter,
Calculated from Calibration Experiments

Run #	α Btu/hr°F	β Btu/°F	γ Btu/hr°F	P l/hr	W °F/hr
1	39.18	45.05	1.37	0.90	69.4
2	40.60	40.70	1.37	1.03	79.9
3	39.20	41.00	1.37	0.99	77.9
4	39.70	45.60	1.37	0.90	71.1
5	38.90	49.70	1.37	0.81	64.4
6	40.20	42.40	1.37	0.98	78.5
7	40.30	37.50	1.37	1.11	89.7
8	37.01	53.75	1.37	0.72	55.09
9	44.66	55.18	1.37	0.82	62.95
10	36.95	41.25	1.37	0.93	72.97
11	40.62	44.91	1.37	0.94	73.87
12	37.10	43.72	1.37	0.88	70.00
13	39.03	40.56	1.37	1.00	79.73
14	39.24	46.41	1.37	0.88	70.70
15	41.78	37.52	1.37	1.15	93.04
<hr/>					
$\alpha_{av.} = 39.57 \pm 1.73 = 39.57 \pm 4.37\%$					
$\beta_{av.} = 44.59 \pm 4.96 = 44.39 \pm 11.2\%$					
$\gamma_{av.} = 1.37$					
$P_{av.} = 0.936 \pm 0.109 = 0.936 \pm 11.2\%$					
$W_{av.} = 73.95 \pm 9.46 = 73.95 \pm 12.8\%$					

versus $\exp(-Pt)$, that is, $T_0 - W/P$, can be obtained. Since P is known from previous calibration measurements, W can be calculated. The rate of heat given off from the human body in the state, Q_3 , can be calculated from a rearranged form of equation 7.10, that is

$$Q_3 = W\beta - \alpha T_0 - \gamma T_1 \quad (7.20)$$

(α and β may change slightly since the heating mantle and human body have different dimensions and thermal capacities.)

The basal metabolic rate, $(BMR)_{exp}$, of the human subject can be obtained as follows:

$$(BMR)_{exp} = Q_3 + Q_v \quad (7.21)$$

where

Q_3 = net rate of body heat released to surroundings

Q_v = rate of latent heat absorbed as a result of water evaporation from the skin and the internal surfaces of the body

Figure 7-4. Calibration Curve for the SKAN-FLO Flowmeter

The Q_v quantity can be calculated as shown below.

Let
 l_1 = barometric pressure
 T_{d1} = inlet dry-bulb air temperature
 T_{d2} = outlet dry-bulb air temperature
 P_{s1} = vapor pressure of water at T_{d1}
 P_{s2} = vapor pressure of water at T_{d2}
 H_{r1} = relative humidity inside the calorimeter at the beginning of the measurement and equal to the inlet air humidity
 H_{r2} = relative humidity inside the calorimeter at the end of the measurement
 P_{w1} = partial pressure of water inside the calorimeter at the beginning of the measurement and equal to the partial pressure of water in the inlet air
 P_{w2} = partial pressure of water inside the calorimeter at the end of the measurement

Z_1 = pounds of water vapor per pound of dry air
inside the calorimeter at the beginning of the measurement
and equal to the inlet air value

Z_2 = pounds of water vapor per pound of dry air
inside the calorimeter at the end of the measurement

ΔH_v = average heat of vaporization of water between
 T_{d1} and T_{d2}

$\dot{m}$ = mass flow rate of dry air

We know that

$$P_{w1} = P_{s1} \times H_{r1} \quad (7.22)$$

$$P_{w2} = P_{s2} \times H_{r2} \quad (7.23)$$

$$Z_1 = P_{w1} / (P_{t1} - P_{w1}) \quad (7.24)$$

$$Z_2 = P_{w2} / (P_{t1} - P_{w2}) \quad (7.25)$$

and can therefore calculate Q_v as

$$Q_v = \dot{m}(Z_2 - Z_1)(\Delta H_v) \quad (7.26)$$

Thus equations 7.20 through 7.26 are the working equations
for human subject experiments.

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ABSTRACT

EFFECT OF TREADMILL RUNNING EXERCISE AT 25% AND 75% OF
MAXIMAL OXYGEN CONSUMPTION ON POST-EXERCISE RESTING
METABOLIC RATE

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Elevated metabolic rate and caloric expenditure following aerobic exercise for post-exercise periods up to twenty-four hours have been reported in previous studies. In the present study, following separate treadmill running bouts of 25% and 75% $\dot{V}O_2\text{Max}$, the post-exercise metabolic rates of eight males and seven females were studied in a calorimeter for twenty-four hours. Mean metabolic rates of males and females were reported respectively as follows: a) immediate post-exercise period at 25% $\dot{V}O_2\text{Max}$ were 9% and 30% (8.76 and 24.19 kilocalories) above pre-exercise values, b) three hours post-exercise at 25% $\dot{V}O_2\text{Max}$ were 16.3% and 16.56% (15.81 and 13.33 kilocalories) above pre-exercise values, c) six hours post-exercise at 25% $\dot{V}O_2\text{Max}$, mean male metabolic rate declined to below pre-exercise values, but female metabolic rate remained elevated by 10.16% (8.19 kilocalories), and d) twenty-four hours post-exercise at

25% $\dot{V}O_2$ Max were respectively elevated by 5.16% and 27.20% (5.00 and 21.92 kilocalories). Similarly, mean metabolic rates of males and females following exercise at 75% $\dot{V}O_2$ Max were: a) 20.35% and 28.17% (20.20 and 22.51 kilocalories) respectively immediate post-exercise above pre-exercise values, b) three hours post-exercise remained elevated by 7.14% and 1.06% (7.09 and .85 kilocalories), and c) six and twenty-four hours post-exercise values returned to below the mean pre-exercise metabolic rate. Significant differences in metabolic rate patterns were observed as: a) between 25% and 75% $\dot{V}O_2$ Max treatments and Control group ($p < .001$) and b) between the patterns of post-exercise metabolic rate between sexes ($p < .014$). The 25% and 75% $\dot{V}O_2$ Max treatments, as well as the Control group, differed significantly in post-exercise metabolic rate patterns for twenty-four hours. Significant changes occur in post-exercise metabolic rates in males and females as a result of different intensities of aerobic exertion, but the time of duration of metabolic rate was not different between 25% and 75% treatments among males. Elevation in metabolic rate persists three and six hours post-exercise, with females maintaining an elevated metabolic rate for a longer period of time than males to low intensity exercise. The Calorimeter method of metabolic rate assessment produced an r of .829 when post-exercise values

were compared with oxygen consumption results.