A laboratory manual for undergraduate physiology of exercise

by Carl Leslie Dalmata

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Physical Education
Montana State University

Abstract:
The general purpose of this investigation was to construct a laboratory manual to accompany the lecture portion of the undergraduate Physiology of Exercise course at Montana State University. The general procedure that the investigation followed in developing the laboratory manual was to:
Interview - The class instructor was interviewed to provide the basic direction for the investigation.

Survey - The survey covered existing course material, physiology of exercise laboratory manuals, textbooks and related sources.

Select - The selection of demonstrations was made in conjunction with the class instructor and determined by the following criteria: clarity of the physiological principle to be demonstrated, simple to perform, completion time within the length of a laboratory class period and use common or easy to construct laboratory equipment.

Design - Demonstrations were designed within the above limitations by using either existing demonstrations, adapting demonstrations or creating new demonstrations from theoretical information.

Acquire - The acquisition of equipment to perform some demonstrations necessitated buying, altering, building or borrowing the equipment.

Test - Demonstrations and equipment were tested to verify their consistency of results, time of performance and clarity of the physiological principle.

Write - All demonstrations were then written into manual form. Each demonstration presented the student with the purpose and theoretical background of the laboratory. Pertinent physiological principles were emphasized to clarify the text and lecture presentations. Sequential directions enabled the student to follow demonstrations and/or perform experimental procedures. Each laboratory concluded with a summary sheet(s) to demonstrate comprehension of the concepts illustrated.

The areas of physiology selected for these laboratory demonstrations were: the voluntary muscle system, the nervous system, the cardiovascular system, respiration, exercise metabolism, heat and humidity effects, training effects, body composition and nutrition.

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Signature Carl Leslie Palmito

Date June 8, 1980

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PHYSIOLOGY OF EXERCISE

by

CARL LESLIE DALMATA

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Physical Education

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Bozeman, Montana

June, 1980

ACKNOWLEDGEMENTS

The investigator would like to express his sincere appreciation and thanks to Dr. Robert Schwarzkopf for his contributions, encouragement, time and effort in reading and correcting the original manuscript but most of all for his insistence to achieve quality.

A special note of thanks to Gordon Williamson for his advice and help on technical equipment.

An extra special note of thanks to my wife, Linda, for her help, patience and understanding allowing for the completion of this investigation.

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ABSTRACT

The general purpose of this investigation was to construct a laboratory manual to accompany the lecture portion of the undergraduate Physiology of Exercise course at Montana State University. The general procedure that the investigation followed in developing the laboratory manual was to:

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CHAPTER 1

INTRODUCTION

Each teacher places varying amounts of emphasis on the components that compose a course. One of the tools an instructor uses to impart information about these components is the course textbook and/or laboratory manual. Every textbook and laboratory manual also highlights select areas of material over that of others. This situation often causes the instructor to use a number of sources. Multiple sources cause the student extra time, expense and confusion. This situation could be avoided to a large extent with one source of information that paralleled class presentation.

Statement of the Problem

The general purpose of this study was to design laboratory demonstrations to accompany the lecture topics in the undergraduate Physiology of Exercise course at Montana State University.

Specifically, this study was to survey existing physiology laboratory manuals, select appropriate experimental concepts, design and/or modify laboratory demonstrations and if necessary, design, construct and/or modify equipment needed to perform the laboratories. The final problem was to write and collate a physiology of exercise laboratory manual that would clarify the student's learning of the material presented in lecture and the course textbook for the undergraduate Physiology of Exercise course at Montana State University.

Delimitations

The study was delimited to nine major areas of exercise physiology to coincide with the instruction of the undergraduate class of Physiology of Exercise at Montana State University: the voluntary muscular system, the nervous system, the cardiovascular system, the respiration system, exercise metabolism, the effect of heat and humidity on physical performance, effects of training on physical performance, determination of body composition and nutritional inventory. The study was performed during the 1979-80 academic year.

Limitations

This study was limited by the following:

1. The equipment already available at Montana State University or which could be constructed at little expense by the author or a University shop.
2. The time available during the University quarter of class instruction for completion of the laboratories.
3. The clarity of purpose, consistency of outcome and the ease of presentation of each laboratory.

Justification

The clarity and in part the success of any form of instruction is dependent on the materials used to present the information. The course instructor said, "The information needs to be presented in a logical, concise and meaningful manner if the student is to comprehend its significance." (Schwarzkopf, 1979) (57)

To date, the Physiology of Exercise class at Montana State University does not have a single laboratory manual that the student can use. As a result, a number of supplementary materials are used. The use of these supplementary materials requires the student to spend time in the Library or to share the resources in the laboratory. Schwarzkopf states,

> Existing physiology laboratory manuals do not parallel the structure of the class presentation here at Montana State University and many of the manuals are either outdated or use equipment that we do not have. (Schwarzkopf, 1979) (57)

With the creation of a single laboratory manual for the Physiology of Exercise class the above problems should be eased and the class become more effective.

CHAPTER 2

METHODS AND PROCEDURES

The procedures used to develop a laboratory manual for the Physiology of Exercise course at Montana State University are presented in the following chapter. These procedures were separated into two phases: 1. the steps in selection of the specific laboratory experiments and demonstrations to fit the course requirements and 2. the origination, construction and/or modification of those unique aspects of the manual by the investigator.

Laboratory selection. The following sequence of steps was followed to arrive at the nine laboratories contained within Chapter 3.

1. Interview - The initial step was that of an interview with the instructor. From the interview evolved a formulation of physiological concepts that needed to be demonstrated, an understanding of the instructor's major intent in the presentation of these demonstrations, how the class was to use and build on these demonstrations and an understanding of some of the past problems that had occurred with the use of existing demonstrations.

2. Survey - A survey of related materials followed covering existing laboratory demonstrations currently used, the course textbook, physiology laboratory manuals, other physiology textbooks and any related journals, periodicals or research information that might prove useful.

3. Selection - A selection was made from the above sources to demonstrate the physiological concepts outlined in the interview phase. Selection was restricted to laboratory demonstrations that could meet the following criteria:

a. demonstrate clearly one of the physiological concepts,

b. be simple to perform,

c. be able to be completed within the time available during a University class instruction period.

d. use equipment already available at Montana State University or which could be constructed or built at little expense by the author or a University shop.

4. Design - There remained a need to create laboratory demonstrations to present the concepts which could not be demonstrated from an existing source.

5. Acquisition - Acquisition of equipment to perform the designed demonstration necessitated buying, altering, building or borrowing the equipment needed.

6. Testing - With the completion of the above steps, the investigator tested the laboratory demonstrations and equipment to verify their consistency of results, their time of performance and their clarity of demonstration of the physiological principle.

7. Writing - The final step was to write the laboratories into a manual form. Each laboratory presented the student with the purpose and

theoretical background of the laboratory. Specific pertinent physiological principles emphasized and clarified text and lecture presentations. Sequential directions enabled the student to follow demonstrations and/or perform experimental procedures. Each laboratory concluded with a summary sheet(s) to demonstrate comprehension of the concepts illustrated.

Unique contributions. The investigator was responsible for developing all or parts of some demonstrations and for adapting previously existing demonstrations. Each demonstration will be discussed relative to its construction, how it originated or modifications made in order to meet existing constraints. These aspects will help the reader understand an integral part of this investigation.

Principle of leverage. A simple manual goniometer was made to demonstrate the principle of mechanical advantage as it relates to joint angle (see Appendix A).

Measurement of power. The Arm Ergometer and Movement Timer (see Appendix A and Figure 1.3) were altered by adding two micro start-stop switches and a timer stop bolt to fix a specified movement distance and measure the time required to move a variable resistance over that distance.

Muscle electrical activity. The Transmitter, Receiver and Physiograph (see Appendix A and Figure 2.1) was used to telemeter and record muscle action potentials. Testing disclosed that the instrument was unsuitable for quantitative information but did clearly illustrate the electrical activity of contracting muscles.

The effect of heat and humidity on physical performance. The variables that needed to be controlled and measured within the demonstration of the effect of heat and humidity on physical performance were:

1. heart rate,
2. a reproducible physical performance,
3. air temperature,
4. humidity, and
5. body temperature.

Existing equipment was used to measure the heart rate and provide a reproducible workload. A vinyl suit was purchased to produce an increase in body temperature and surround the body with a relative humidity of one hundred percent (100%). The Mechanical Engineering Department of Montana State University assisted by suggesting the use of and loaning a thermo senser, thermocoupler, and digital thermometer combinations (see Fig. 6.1, page 78) to measure necessary temperatures.

Nutritional inventory. This laboratory was unique in that no experimental procedure was used. Each student completes a nutritional inventory and energy use daily log. These standard charts were then used to analyze the following nutritional factors:

1. energy balance,
2. dietary lipids,

3. percentage of simple and complex carbohydrates,
4. selected nutritional factors most frequently deficient,
5. dietary salt, and
6. nutritional quality of food items.

Chapter 3 will present the Laboratory Manual for the Physiology of Exercise course at Montana State University.

CHAPTER 3

LABORATORY MANUAL PRESENTATION

The following laboratory manual is divided into nine laboratory demonstrations. Each demonstration is designed to aid in the student's comprehension of an area of physiology of exercise. The nine laboratories are as follows:

Laboratory 1 - Properties of the Voluntary Muscular System,

Laboratory 2 - The Nervous System,

Laboratory 3 - The Cardiovascular System,

Laboratory 4 - Respiration,

Laboratory 5 - Exercise Metabolism,

Laboratory 6 - Effect of Heat and Humidity on Physical Performance,

Laboratory 7 - Training Effects on Physical Performance,

Laboratory 8 - Determination of Body Composition,

Laboratory 9 - Nutritional Inventory.

LABORATORY 1

PROPERTIES OF THE VOLUNTARY MUSCULAR SYSTEM

Purpose

The purposes of this laboratory are two-fold:

1. to develop an understanding of how strength is affected by:
    a. the number of muscle fibers,
    b. recruitment of muscle fibers,
    c. the type of muscle fiber, and
    d. anatomic leverage factors.
2. to demonstrate the fundamental properties of:
    a. concentric contraction,
    b. isometric contraction,
    c. eccentric contraction, and
    d. power.

Background

The muscle fiber is the basic unit of muscle contraction. It is within the fiber that the shortening or attempted shortening takes place. As each individual muscle fiber contracts, it exerts a force at both ends which is transmitted in series to other muscle fibers or connective tissue that is attached to the fiber.

Testing of muscle capacity is perhaps the oldest of all physiologic measurement. A cave man can be imagined lifting a rock and defying others to exceed his display of strength. Common measurements of skeletal muscle capacity have progressed from this crude measuring system to only more sophisticated means of providing resistance and recording the results. Common terms used to classify and measure muscle performance are: strength, endurance and power. Each parameter is defined in the following paragraphs.

Strength. "Muscular strength is best defined operationally as the greatest amount of force that muscles can produce in a single maximal effort." (21:90)

Endurance. "The ability to persist in physical activity, to resist muscular fatigue, is referred to as endurance." (15:410)

Power. Power (P) is the rate of doing work (W) or the W per unit of time (t), (P = W/t). The rate is defined as the speed with which a task is completed. The W is the product of the force (F) or strength multiplied by the distance (d) through which the force acts, ($W = F \times d$; therefore, $P = \frac{F \times d}{t}$). (15:200-1) P is also a product of the F times the velocity (v) since $v = d/t$.

This laboratory will demonstrate three types of muscle contraction: concentric, isometric and eccentric. In addition, two relationships will be measured: 1. the force of concentric contraction and power and 2. the force of isometric contraction and the joint angle.

Muscle Force Factors

The total force that a muscle can generate for external use is dependent on five factors:

1. the number of fibers contracting,
2. the frequency with which the fiber is stimulated,
3. the fiber type,
4. the angle of pull between the muscle and the bone to which it is attached and
5. the length of the muscle.

Number of fibers. The number of fibers contracting directly and proportionally relates to strength. This is termed spatial summation. The brain forms an estimation of the amount of tension necessary for a given action and an appropriate summation of fibers is determined. This phenomena is not foolproof as demonstrated by lifting an empty box thought full.

Frequency. The frequency of stimulation or temporal summation produces more tension due to the addition of high threshold fibers and by maximizing the tension in each spacially summated fiber. (For a more complete description see pages 51-52 of Physiology of Exercise third edition by Herbert A. deVries.)

Summation of muscle fibers can be modified by psychological variables. Illness or depression will reduce maximum strength. Excitement (e.g., competition), fear, rage and other emotional factors will increase muscular response. Blood concentration of epinepherine is the primary reason for the phenomenon of the increase in muscular response.

Fiber type. There are two types of muscle fibers in human muscle (sometimes a third intermediate variety is listed), known as fast twitch fibers (FTF) and slow twitch fibers (STF). The terms fast and slow refer to the contracting characteristics of the muscle fiber (see Table 1.1). Fiber types have fixed hereditary characteristics. Although one fiber type can not change into another fiber type, training can modify its performance capacity.

Table 1.1

ATTRIBUTES OF MUSCLE FIBER TYPE[20]

Characteristic	FTF	STF
Myosin ATPase Activity	Greater	Less
Activities of Enzymes for Anaerobic Glycogen and Glucose Breakdown	Greater	Less
Number of Mitochondria	Less	Greater
Activities of Enzymes of Krebs Cycle Electron Transport System	Less	Greater
Number of Capillaries per Fiber	Less	Greater
Activities of Enzymes for Fatty Acid Breakdown	Less	Greater
Recruitment during Short Duration Maximal Exercise	Greater	Less
Recruitment during Submaximal Exercise	Less	Greater

20. Lamb, David R., Physiology of Exercise, Responses and Adaptations, Macmillan Publishing Co. Inc., New York, New York. 1978.

Strength is measured over a short duration of time under anaerobic conditions. These conditions favor FTF, thus the more FTF within the muscle the greater the strength of the muscle. The more STF the greater the endurance, for STF supply the bulk of the contractual tension at submaximal loads.

Angle of pull. Effective muscular force is also related to the angle between the muscle and the bone to which it is attached. This is an important consideration when dealing with the principles affecting muscular force. A maximum force at the end of the lever can only be exerted at a particular angle, that of 90^{o} between the muscle and bone. At any angle less than 90^{o} the muscular force is used in part for stabilization of the joint or destabilization if greater than 90^{o} as illustrated by the "C" force vector in Figure 1.1. The 90^{o} angle refers to the angle between the muscle and the bone and does "not necessarily" mean that the angle between the forearm and the upper arm is also 90^{o} as depicted in the center example of Figure 1.1. Figure 1.1 is a pictoral representation of the fundamental forces present in the arm under a work situation. Force vector "A" represents the resultant force generated by the muscle, vector "B" the rotary force being applied and vector "C" the stabilizing or destabilizing force present at that particular angle. The force vectors are lifted and moved to form a force vector triangle in order to show the equality of the force applications between the resultant (the muscular force vector A) and

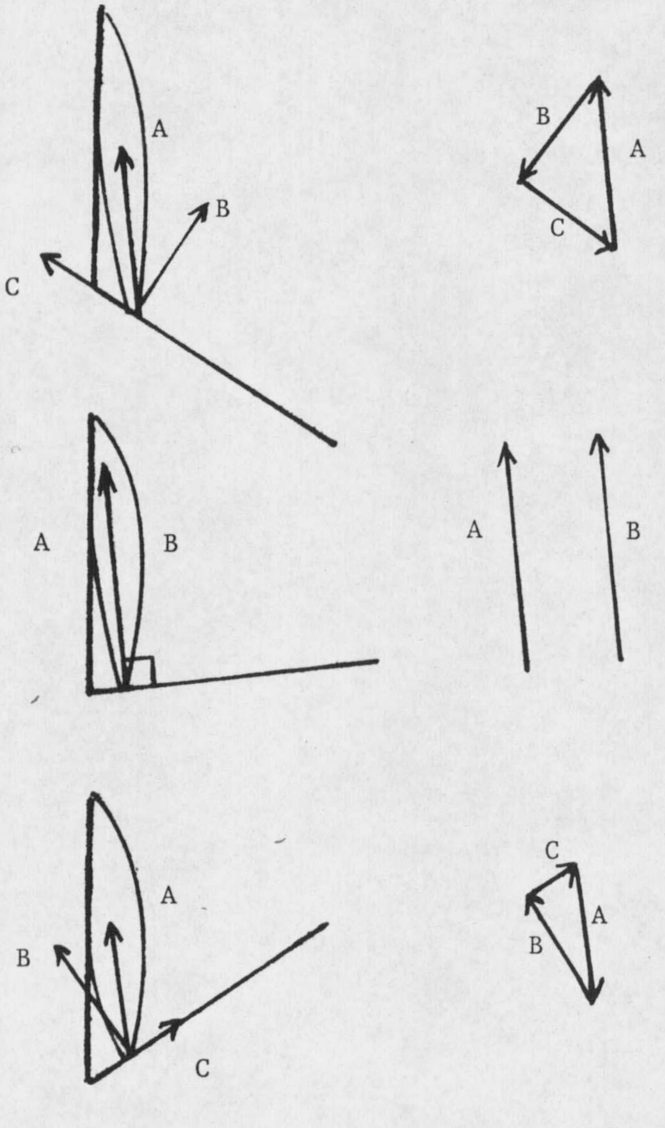


Figure 1.1

EFFECT OF THE ANGLE OF PULL OF A MUSCLE,"A" IS THE RESULTANT MUSCLE FORCE, "B" THE ROTARY FORCE AND "C" THE WASTED STABILIZING OR DESTABILIZING FORCE.

the two other forces. Notice that in the center example of Figure 1.1 force C is missing. The absence of force C illustrates that all of the muscular force is used for pure rotation. This means that force C in the top and bottom examples of Figure 1.1 represent wasted force as far as external work is concerned.

Muscle length. The tension or force that can be generated within the muscle itself is directly related to the length of the muscle and its fibers. This is due to the physical composition and functioning of the muscle fibers. The greater the muscle length the greater the tension that can be produced within the muscle up to certain limits. (For a more complete description see pages 57-60 of Physiology of Exercise third edition by Herbert A. deVries.)

Types of Muscular Contraction

There are three types of contraction that the human muscle is capable of: concentric, isometric and eccentric.

Concentric contraction. Concentric (shortening) contractions have the least strength in terms of the maximum resistance in comparison to the other forms of contraction. This relative weakness is due to the continuous reforming and dissolving of the Actin/Myosin bridges. (For a more complete explanation, refer to H.E. Huxley's theory on page 24 of Physiology of Exercise, third edition by Herbert A. deVries.) Concentric contraction strength will be measured in this laboratory by the addition of weight to the Arm Ergometer until the test subject can no longer lift the load. The largest amount of weight that the subject lifts will be considered for this laboratory as their maximum concentric strength.

Isometric contractions. Isometric (static) contractions involve the shortening of the muscle fibers only to eliminate the elastic component of the muscle and then the fibers will remain in a fixed position. This fixed position does not require the formation of new Actin/Myosin bridges. Isometric strength will be demonstrated by adding weight to the Arm Ergometer until the subject can no longer prevent the weight from descending. The greatest amount of weight that the subject can hold will be considered a measure of their isometric breaking strength at that joint angle (90^o).

Eccentric contractions. Eccentric (elongation) contractions have the greatest strength in terms of the maximum resistance in comparison to the other forms of contraction. The muscle tension is a maximum contraction resisting an external force acting to lengthen the muscle. The external force must break the Actin/Myosin bridges within the muscle fibers which requires more external force than that applied during a concentric contraction (reforming bridges) or an isometric contraction (maintaining a static position). Eccentric strength will be approximated by the maximum amount of weight that the subject can lower "with control." Weight will be added until the subject can no longer control or slow the load's descent.

Muscular Performance and Power

As described earlier, power (P) is the work (W) per unit of time (t), P = W/t or $P = \frac{F \times d}{t}$ since W equals the force (F) times distance (d). The P produced can then be increased if F or d is increased. An increase of P is also possible by a reduction in the t. The concept of power will be demonstrated in this laboratory by a measure of the changes in F, t and d during concentric contraction.

Directions for Demonstration

The following equipment will be needed to demonstrate concentric, isometric and eccentric contractions and muscle performance versus power:

Arm Ergometer,

weights,

manual Gonimeter,

movement timer.

Ideally, a complete recovery is allowed between contraction trials. For expediency a two-minute rest will be used between contractions.

The equipment is set up as illustrated in Figure 1.2 for the Power demonstration. A different subject will be used for each section of the laboratory.

Concentric strength. Concentric strength will be determined for this laboratory by the following steps:

1. set the first resistance by placing weights in the load pan,

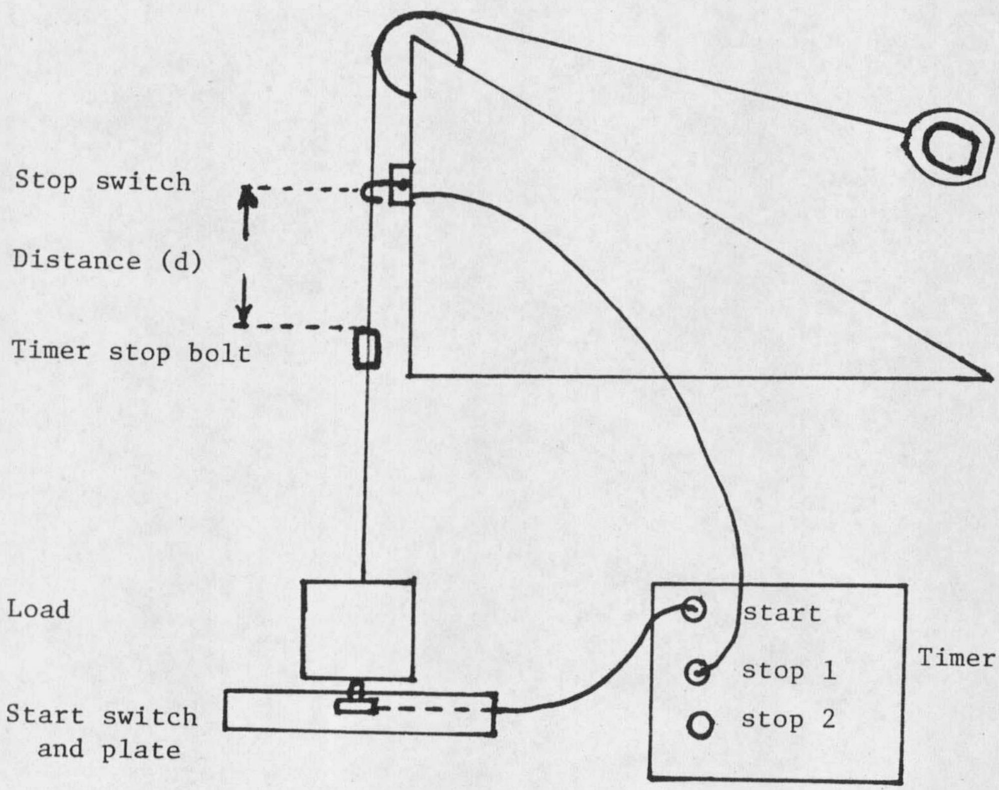


Figure 1.2

EQUIPMENT FOR POWER DEMONSTRATION

2. have the subject lift the resistance with elbow flexion only starting with the arm flat on the table top,
3. record the resistance and add more weight,
4. repeat steps 3 and 4 until the subject can not lift the resistance.

Isometric strength. The isometric breaking strength will be determined for this laboratory by the following steps:

1. set the first resistance near that estimated for a maximum load used for concentric contraction,
2. have the subject hold the resistance at an elbow joint angle of 90^{o} measured with the manual goniometer.

   Note: The subject must hold the resistance so that the pull of the resistance is perpendicular to their forearm.
3. record the resistance and add weight to the load pan,
4. repeat steps 2 through 4 until the subject can no longer hold the load at the desired angle.

Eccentric strength. Eccentric strength will be demonstrated for this laboratory by the following steps:

1. use the maximum approximate load used for isometric strength from the preceding demonstration,
2. the assistant lifts the load so that the subject's arm may flex to the maximum flexed position,
3. have the subject slowly lower the load to the floor,

4. record the resistance and add weight,

5. repeat steps 2 through 4 until the subject can no longer slow the load's descent.

Power. The subject's peak power will be determined for this laboratory by the following steps:

1. check the switches, timer and timer stop bolt distance making sure that all parts are working properly and connected as indicated in Figure 1.2;

2. measure the distance (d) from the timer stop bolt to the timer stop switch and record it,

3. set the first resistance at approximately 20 pounds,

4. have the subject lift the resistance (with complete elbow flexion only), as fast as possible,

5. record the time (t) from the Movement Timer required for the subject to generate the force (F) to move the resistance through the fixed distance (d).

6. repeat steps 2 through 4 for the increases in resistance at 5 pound increments,

7. calculate the power for each resistance from the following $P = \frac{F \times d}{t}$ and plot the results.

   Example: $P = \frac{F \times d}{t}$ $\quad P = \frac{20 \text{ lbs. } \times 1 \text{ ft.}}{.5 \text{ sec.}}$ $\quad P = \frac{40 \text{ ft. lbs.}}{\text{sec.}}$

Summary Sheet for Laboratory 1

Concentric Strength

Trial #	1	2	3	4	5
Resistance					

Maximum concentric contraction = __________

Isometric Strength

90^{o}

Trial #	1	2	3	4	5
Resistance					

Isometric breaking strength = __________

30^{o}

Trial #	1	2	3	4	5
Resistance					

Isometric breaking strength = __________

120^{o}

Trial #	1	2	3	4	5
Resistance					

Isometric breaking strength = __________

Eccentric Strength

Trial #	1	2	3	4	5
Resistance					

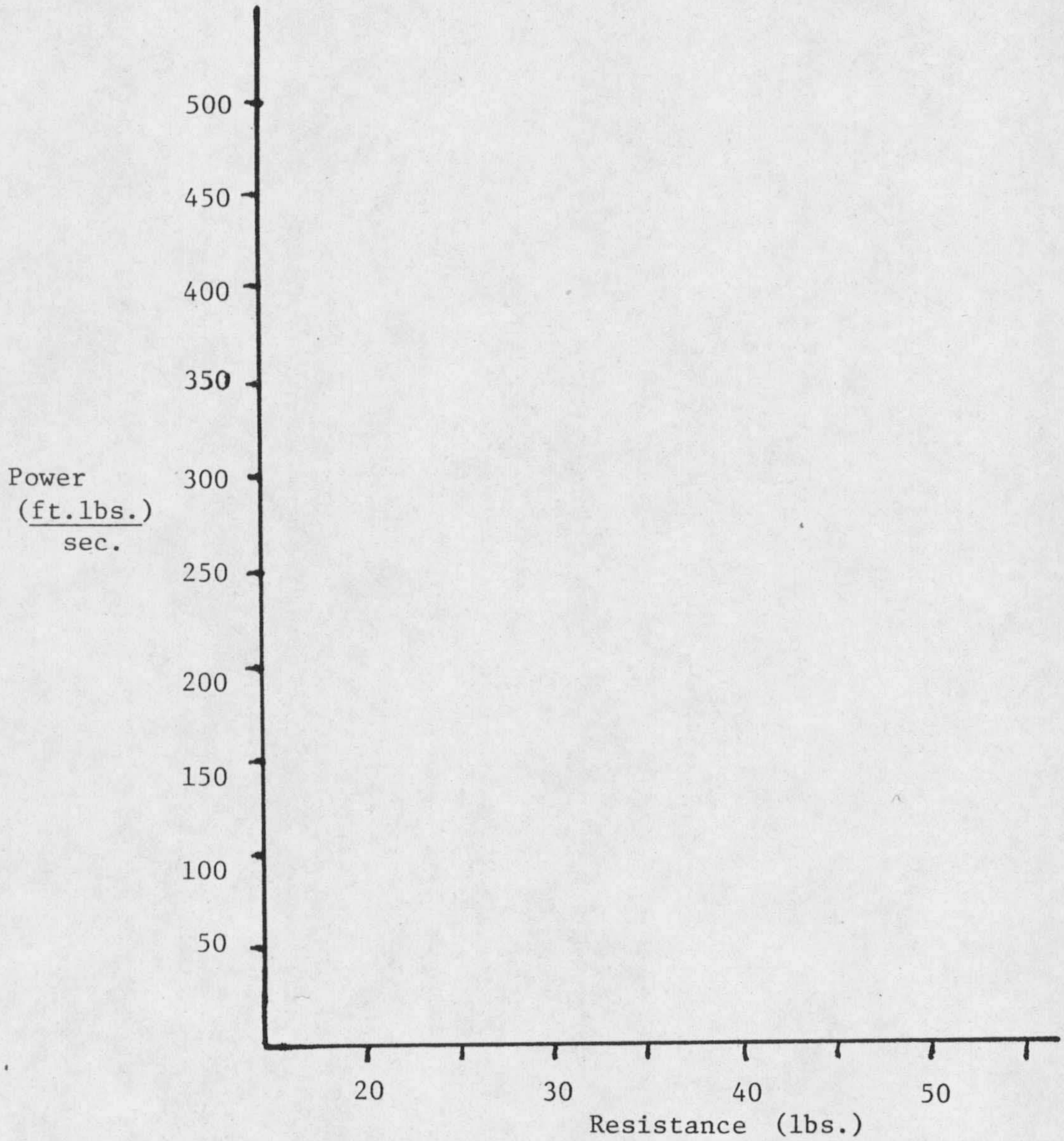
Eccentric strength = ________

Power

Resistance	20	25	30	35	40
Time (t)					
Power					

d = ________

Summary Sheet Laboratory 1



LABORATORY 2

THE NERVOUS SYSTEM

Purpose

The purposes of this laboratory are to:

1. demonstrate the electrical activity present during muscular action,
2. enable the student to measure nervous system parameters important in sport, i.e. reaction and movement time.

Background

Nervous function is a prerequisite for movement; without nervous stimulation, movement is non-existent. The complexity of the organization of the billions of individual units (cells) and their interconnections may prevent man from ever completely understanding how this wondrous system operates. However, knowledge of some of its properties can aid in a better understanding of how the nervous system relates to exercise.

Electrical activity of muscles. The nervous system operates by electrical activity. This electrical activity is produced by the movement of charged particles across the neuron membrane. These charged particles are due to the high concentration of ions in solution within body fluids. With the movement of these charged particles a nearby disturbance or electrical field is created. The electrical field can be detected by sensitive instruments placed on the surface of the body.

(see Figure 2.1) This laboratory will demonstrate this phenomenon (the electrical activity causing muscular response), by a device that will detect, amplify and mechanically print a pattern of the electrical activity.

Reaction time. Reaction time is defined as ". . . the interval between presentation of the stimulus and the first sign of response." (15:102) A person's reaction time is dependent on a number of factors. The major factors are:

1. the speed of transmission of the afferent or receptor neurons from the sense organ to the cerebral cortex,
2. the time it takes to process the stimulus and form an appropriate response pattern,
3. the speed of transmission of the efferent or effector neurons to the muscles.

Reaction time will be demonstrated in this laboratory by an electronic device which measures response time to a visual signal. (see Figure 2.2)

Movement time. "Movement time is defined as the interval between the start and finish of a given movement." (15:102) Movement time is dependent on a number of factors:

1. the coordination of agonist and antagonist muscles controlling the movement pattern,
2. the type of fiber in the respective muscles (fast or slow

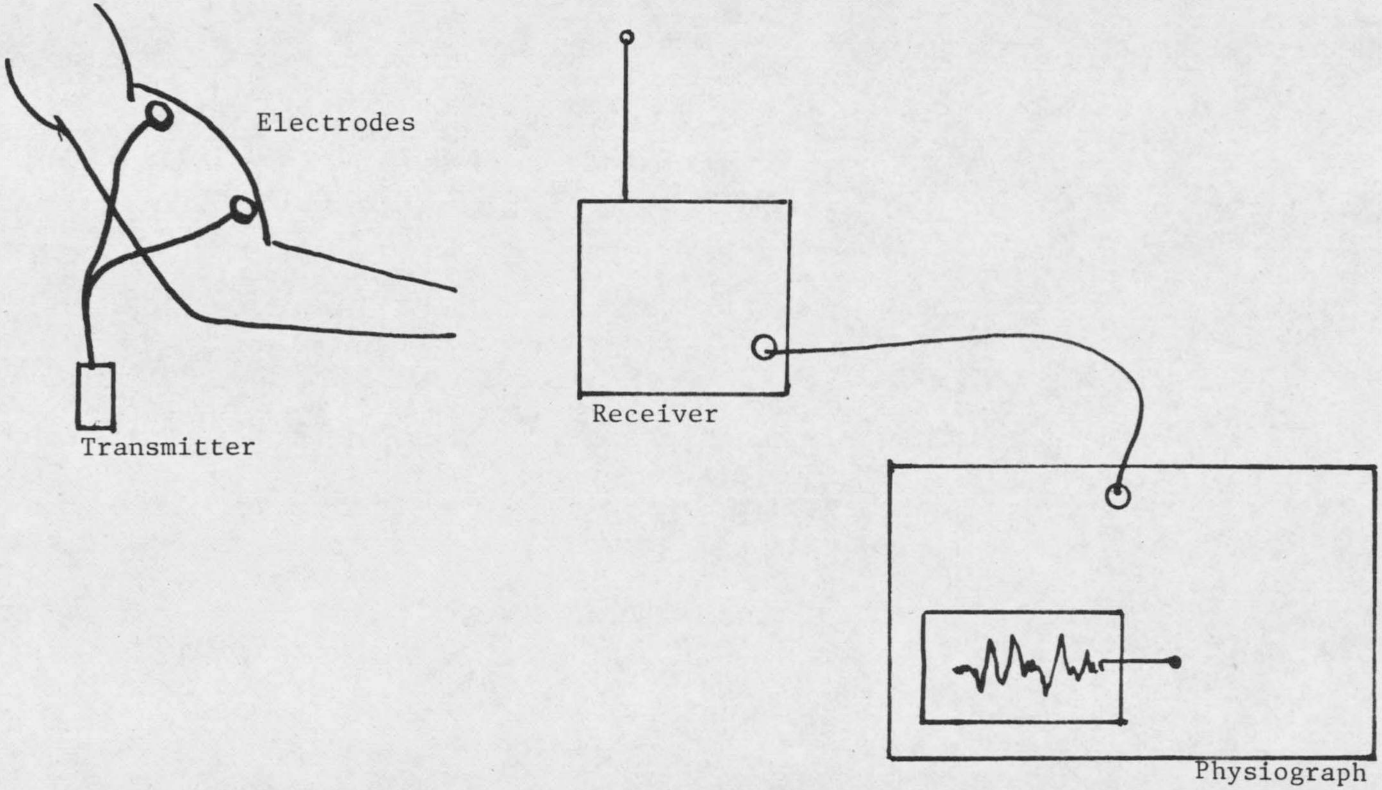


Figure 2.1

DIAGRAM OF MUSCLE, ELECTRODE PLACEMENT, TRANSMITTER, AND PHYSIOGRAPH.

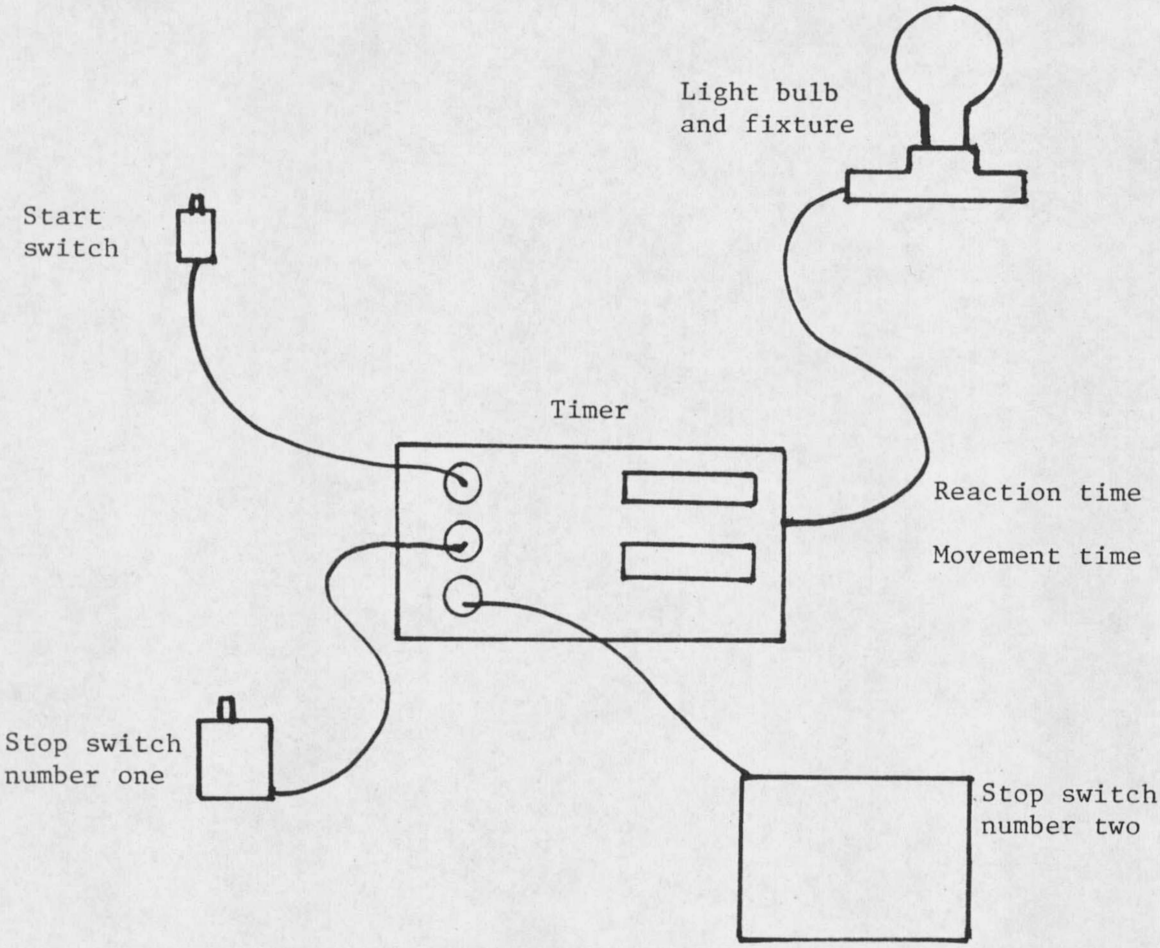


Figure 2.2

REACTION-MOVEMENT TIME MACHINE WITH
VISUAL STIMULUS ATTACHMENT

twitch),

3. the distance (d) that the motion covers,

4. the resistance of the load being moved.

Movement time will be demonstrated by the measure of the time it takes the subject's hand to move between two switches on the Reaction-Movement Time Machine. (see Figure 2.2)

Directions

The following equipment will be needed to demonstrate the electrical activity within the muscle and to find the reaction time and movement time:

Electromyograph (EMG),

Arm Ergometer,

Reaction-Movement Time Machine,

switches (3),

light bulb and fixture.

Electrical activity. The electrical activity within the human muscle will be demonstrated by the following steps:

1. turn on the EMG and allow it to warm up while the skin electrodes are placed on the subject; see Figure 2.1 for the proper placement of electrodes and other equipment.

2. have the subject flex the arm (elbow flexion only) and observe the EMG tracing,

3. place a load on the Arm Ergometer and repeat Step 2,

4. compare the two tracings.

Reaction-Movement time. Reaction time and movement time can be found at the same time if the timer has two readouts. See Figure 2.2 for proper set up of equipment. Each pair of students will perform these steps:

1. have the subject place the hand lightly on stop switch number one,
2. the tester starts the timer and turns on the light bulb by closing the start switch,
3. the subject reacts to the visual stimulus (the lighted bulb) by pressing down on stop switch number one opening the circuit and stopping the timer,
4. the subject then moves the hand to stop switch number two (which has been placed a distance (d) away) as fast as possible stopping the timer,
5. read and record the reaction time (step 3) and movement time (step 4) on the summary sheet.
6. repeat five times, eliminate the fastest and slowest time and average the remaining three.

Summary Sheet for Laboratory 2

Trial #	Reaction Time (seconds)	Movement Time (seconds)
1		
2		
3		
4		
5		

LABORATORY 3

THE CARDIOVASCULAR SYSTEM

Purpose

The purposes of this laboratory are four-fold:

1. to demonstrate the relationship between heart rate (HR) and workload,
2. to understand and measure how vasomotor controls affect blood distribution,
3. to have each student's blood pressure measured using the asculatory method,
4. to understand the importance of a stress test for diagnosing cardiovascular disease.

Background

Factors related to cardiac output. The fundamental relationship governing the heart functioning as a pump is cardiac output (CO) equals the heart rate (HR) times the stroke volume (SV), CO = HR x SV. CO is the volume of blood ejected per unit to time (vol./time), HR is the frequency of the pumping or ejecting of blood and SV is the volume per ejection.

CO is considered the primary limiting factor in the delivery of oxygen to the tissues (5, 15, 21). Tissue oxygen supply limits the energy for aerobic exercise and for speeding recovery from anaerobic exercise. Therefore, it can be understood why a large CO for athletic performance is necessary for every sport that demands a large consistent energy supply and/or a rapid recovery.

From the above relationship, it can be seen that either or both variables (HR and SV) will have a direct effect on CO. Therefore, the larger the SV and the higher the HR the greater the CO and consequently oxygen delivery. Both HR and SV change with exercise and body position. In general when untrained subjects are in a resting horizontal position their SV is at its maximum. If they move to a vertical position their SV drops but the SV can then be increased with exercise to that of the horizontal capacity. Once the horizontal SV capacity is reached no further increase is possible. Therefore, any further increase in CO is due to increased HR. Trained persons' hearts have the ability to increase in SV beyond the horizontal resting capacity and thereby allows a significant increase in the CO potential. These relationships are summarized in Table 3.1 showing the central circulation differences between trained and untrained individuals.

HR increases proportionally with exercise intensity from rest to maximum. This general relationship is modified by these qualifications:

1. at low exercise intensity levels many other factors (emotional, mental, physical etc.) can effect HR,
2. near maximum exercise intensity HR reaches its maximum level, further energy demands are met by an increased reliance on the anaerobic pathway,

Table 3.1

TRAINED VERSUS UNTRAINED RESPONSES[57]

	CO (liters/min	HR (bpm)	SV (ml/beat)	$\dot{V}O_2$ (liters/min)	A-VO_2 (ml/100ml)	$\dot{V}_R$ (liters/min)
Untrained Rest	5.0	72	70	.250	4.5	6
Untrained Max	20.0	200	100	3.00	15	120
Highly Trained Rest	5.0	42	120	.250	4.5	6
Highly Trained Max	38.0	190	200	6.00	16	200
	Cardiac Output	Heart Rate	Stroke Volumn	Oxygen Uptake	Arterio-Venous O_2 Difference	Respiratory Volumn

57. Costill, David, A paper presented at the Sports Medicine Symposium, Tucson, Arizona, November 1979.

3. the form of activity must be rhythmical, i.e. changing intensity or static exercise do not follow this relationship,
4. training does not raise maximum HR to increase CO in a similar manner to SV; rather, resting HR declines increasing the functional capacity or Cardiac Reserve Capacity (CRC).

HR, exercise intensity and a third variable Perceived Level of Exertion (PLE) are all directly related. The subsequent feeling of stress as measured by the Borg Scale of PLE in Table 3.2 demonstrates this relationship. This easily measured parameter (HR) provides a crude but reliable index of the severity of exercise which can have many applications (see Laboratory 7).

Table 3.2

PERCEIVED LEVEL OF EXERTION CHART[37]

HR(bpm)	PLE
60	6 very, very light
90	9 very light
110	11 light
130	13 somewhat hard
150	15 hard
170	17 very hard
190	19 very, very hard

37. Borg, G., "Perceived exertion: a note on history and methods," Medicine and Science in Sports, Vol. 5, p. 90-93. 1973.

Vasomotor control. Blood is transported via the circulatory system composed of a subdividing arterial network to the tissues and a condensing collecting venous return network from the tissues. A property of this "tubing" system is the ability to change diameter thereby controlling the amount of blood delivered and/or the amount of blood contained in that portion of the system. The importance of the later factor is that less blood, therefore less weight, is used to fulfill circulatory functions. By redistributing blood with this diameter control, blood is diverted to active tissue from less active tissue. For example, less blood goes to the kidney and GI tract during exercise so more blood can be channeled to working muscles. This principle will be demonstrated by a common technique used by body builders called "pumping."

Blood pressure. Blood pressure (BP) is hydrostatic fluid pressure normally measured in the arterial portion of the vascular system. BP is proportional to CO and the total peripheral resistance within the system. A total of four variables determines what the pressure is at any given time; Pouiselles formula summarizes the relationship $BP \propto CO \times \frac{L \times v}{D^4}$, where L = length, v = viscosity and D = diameter. (5:147-152) CO is a product of HR and SV described in a previous section. Length (L) changes as an adaptive response to growth, atrophy and/or hypertrophy, i.e. adding or reducing the amount of tissue and therefore, the blood supply to that tissue. Viscosity (v) is the "thickness" of the blood. Viscosity varies with hydration, altitude adaptation and training, all of which are associated with exercise. Diameter (D) is the most important factor as reflected in its exponential value. A small change in D means a large change in resistance to blood flow and therefore BP. From this discussion it can be understood that BP is a highly variable parameter due to the many influencing factors.

Normally, CO is the primary determinate in BP change. However, D is also an important control as illustrated by two abnormal responses, shock and hypertension. Shock or emotional shock (turning pale) is an inappropriate vasodilation causing blood to pool in dialated blood vessels. With less blood supply to the brain, fainting can result. Hypertension (high BP) can be caused by a persistent general vasoconstriction. The cause of this is generally unknown (essential hypertension). Stress can cause a temporary vasoconstriction and it is theorized that repeated prolonged stress may alter the vasomotor control center.

BP is not a fixed value but rather a continually changing value during the repetitive rhythmical muscular contractions and relaxations of the heart; one repetition of this muscular action is termed a cardiac cycle. There is a high (peak or systolic) and a low (diastolic) value during each cardiac cycle. These values are the ones measured and called BP. Left ventricular pressure forces an ejected volume (SV) into the aorta with each beat. This volume and those preceding it fill the large arteries causing a swelling or stretching of the elastic properties of the arterial wall. Two important results are derived from this:

1. the pressure is "damped" to a lower value than what it would be if the vessels were rigid,
2. the elastic recoil changes the pulsatile flow within the arteries to a continuous flow at the capillary level.

The primary changes due to exercise are in CO response as previously discussed and in the vasomotor redistribution. The vasomotor redistribution factor causes a lowering of resistance within the vessels leading to a smaller change in BP than if CO were the only changing variable.

It can further be pointed out that left ventricle pressure must exceed the lowest pressure in the large arteries before ejection is possible. If diastolic pressure rises (for example with age and the accompanying changes in elasticity), the left ventricle must work (contract) harder to eject blood. Therefore, it is said that the work of the heart increases in response to the increased diastolic pressure resistance.

In the third portion of the laboratory the student will learn to measure BP using the asculatory method.

Stress Testing

The American Heart Association estimates that 350,000 people die of heart attack each year. (49:1) Heart attack is the cause of death but high blood pressure, over weight, poor diet, lack of exercise, smoking and excessive stress are considered some of the factors related to and/or accelerating the disease.

Most people are unaware that they may be vulnerable or already have cardiovascular disease. The first symptom could be fatal and any symptom indicates an advanced state of this chronic disease.

Stress testing by trained personnel is a means of monitoring the heart under exercise conditions. Most often a treadmill is used to supply the exercise stress and a electrocardiograph (ECG) to record heart electrical response. The ECG plus blood pressure response under increasing exercise stress allows a cardiologist to learn of potential cardiac abnormalities before they occur. Figure 3.1 shows an illustration of a stress test and Figure 3.2 shows an example of a normal ECG pattern that would be seen during the test. The student will be able to observe a similar ECG pattern during the first part of this laboratory.

Directions

The following equipment will be needed for each part of this laboratory:

Part 1. bicycle ergometer, stop watch and electrocardiograph,

Part 2. tape measure, stop watch and weights,

Part 3. stethoscope and sphygmomanometer.

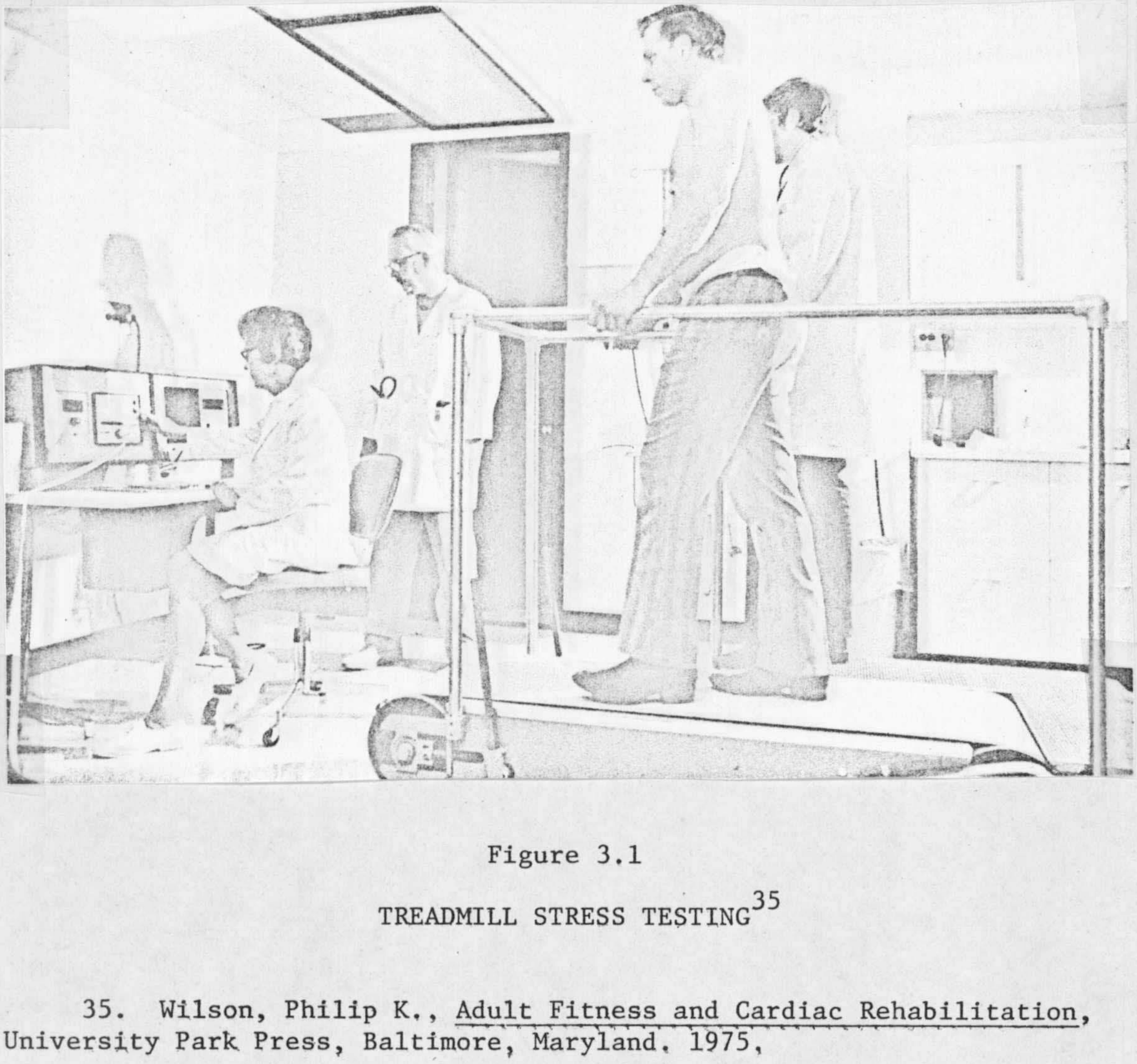


Figure 3.1

TREADMILL STRESS TESTING[35]

35. Wilson, Philip K., Adult Fitness and Cardiac Rehabilitation, University Park Press, Baltimore, Maryland, 1975,

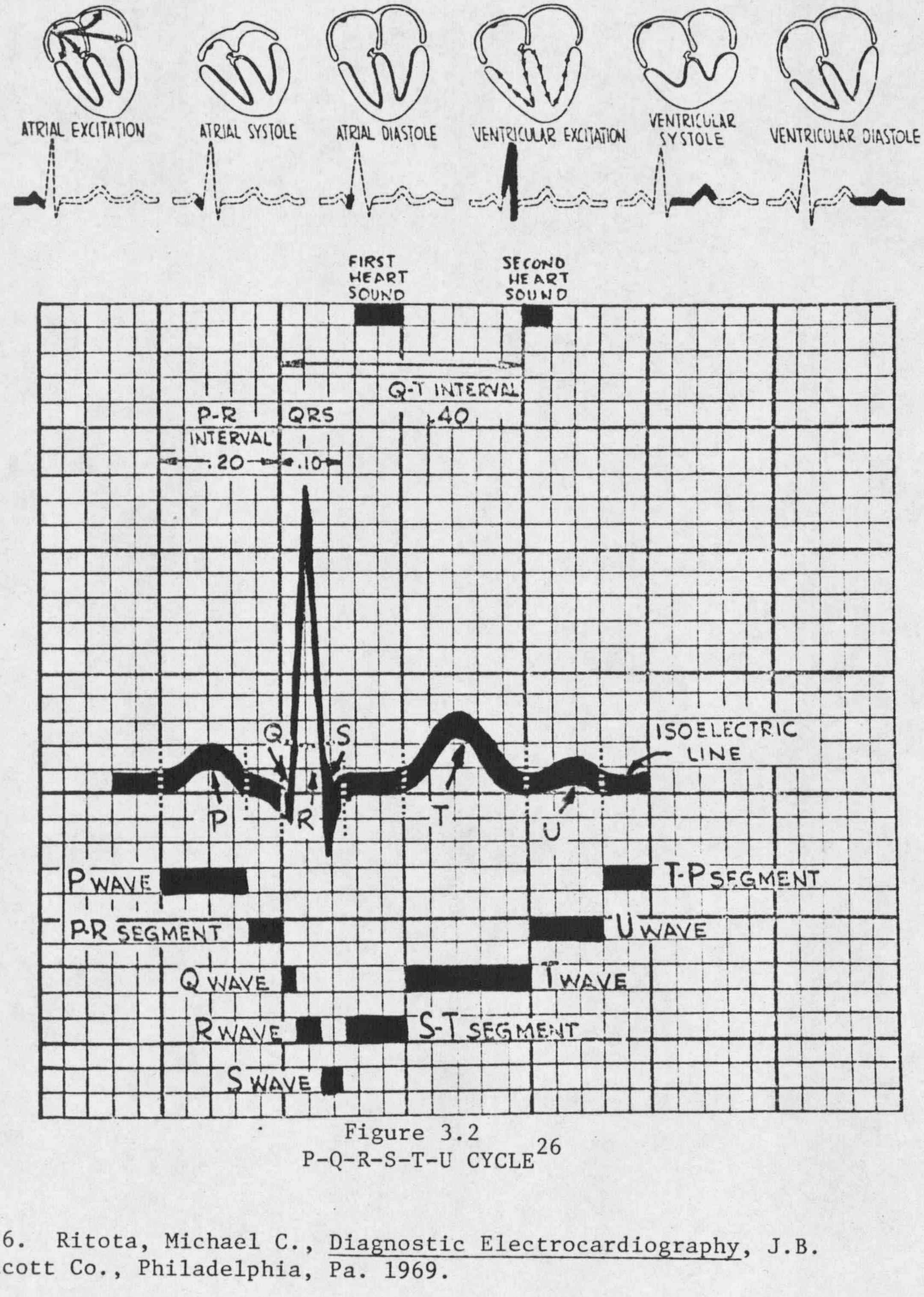


Figure 3.2
P-Q-R-S-T-U CYCLE[26]

26. Ritota, Michael C., Diagnostic Electrocardiography, J.B. Lippincott Co., Philadelphia, Pa. 1969.

Heart rate response to exercise. The following steps are used to demonstrate Part 1 of this laboratory:

1. electrodes are attached to the test subject and electrocardiograph tested for proper function.
2. subject pedals the bicycle ergometer at 1 Kp for two minutes,
3. HR is taken during the last ten seconds of each minute,
4. plot the HR announced by the laboratory instructor on the accompanying graph,
5. the workload is increased by 1 Kp and steps 3 and 4 are repeated until the subject has performed all 5 workloads.

Vasomotor control. The following list of steps will demonstrate vasomotor control:

1. have a partner measure the circumference of your dominant upper arm at its maximum girth while in a relaxed position at your side,
2. record the measurement,
3. rhythmically curl one of the weights (males use the heavier) for two minutes at a rate of approximately one curl every two or three seconds,
4. measure the arm girth in the same manner at the time intervals specified on the laboratory summary sheet.

<u>Measuring blood pressure</u>. The following list of steps are used to measure blood pressure:

1. the subject must be seated with right arm resting relaxed on the chair desk,
2. the sphygmomanometer (hereafter called cuff) is wrapped around the upper right arm above the elbow level and secured with the velcro fastener,
3. the pressure gauge is placed in position on the cuff,
4. the valve on the bulb assembly is closed (clockwise rotation),
5. squeeze the bulb inflating the cuff to approximately two hundred (200) millimeters of mercury,
6. place the stethescope in position in the ears and over the anticubital fossa (elbow crotch),
7. <u>slowly</u> lower the cuff pressure by turning the valve counter-clockwise.
8. the first sound (systolic BP) is the approximate equilization between the cuff and the left ventricular pressure--when the cuff obstruction is not great enough to exceed the left ventricular force on the stationary brachial arterial column and a pulsitile squirting of blood can be heard past the cuff,
9. allow the cuff pressure to continue falling,

10. the "sound" should increase in intensity and then fade; when no further sound can be heard the pressure is noted and recorded (diastolic BP)--at this point the cuff no longer obstructs the forward blood flow, therefore equalizing the minimum elastic recoil force of the large arteries.

Summary Sheet for Laboratory 3

I. HR Response

Workload (W), (Kp)	1	2	3	4	5
Heart rate (HR)					

HR

240
220
200
180
160
140
120
100
80
60
40

1 2 3 4 5

W (Kp)

II. Vasomotor

Arm Circumference:

- Before using weights ________
- Immediately after using weights ________
- 30 seconds after using weights ________
- 1 minute after using weights ________
- 2 minutes after using weights ________

III. Blood Pressure ________/________

LABORATORY 4

RESPIRATION

Purpose

The purpose of this laboratory is to develop an understanding of some fundamental properties of respiration; specifically:

1. the mechanical movement of air (external respiration),
2. respiratory volumes,
3. volume (V_R) versus workload and
4. the standard temperature, pressure and dry (STPD) calculation.

Background

Through the process of respiration gasses are moved in and out of the lungs, exchanged across cell membranes by pressure differences and transported in a fluid medium to and from all body tissues. It is this movement of gasses that sustains life as we know it.

External respiration. Respiration is initiated by muscular contraction producing a mechanical expansion of the thorax. The inspiratory muscles (diaphragm and external intercostal) contract causing the rib cage to expand and diaphragm to descend. The enlarged thoracic volumn produces a partial vacuum in the closed area of the pleural cavity. This partial vacuum creates a pressure gradient between the lungs and the external environment. A gas (air) will then flow from the high pressure area to the lower pressure area to fill the lungs. Air will continue to flow into the lungs until the partial vacuum is eliminated by an equalization of pressure. The pressure gradient is reversed on expiration when the inspiratory muscles relax and elastic recoil of the stretched tissue creates a higher pressure in the thorax than in the ambient environment. Elastic recoil may be aided by the expiratory muscles (internal intercostal and abdominal) under exercise stress.

Respiratory volumes. The lungs consist of a branching system of tubes that subdivide ending in thin walled sacs known as alveoli. Figure 4.1 shows the order of subdivision for this system. This branching system allows for a greater surface area of alveolar wall to surrounding pulmonary capillaries for gas exchange. (see Figure 4.2)

Lung capacities vary between individuals. Volumes, capacities and quantity exchanged over time are measured for their relationship to performance and health. The volumes and capacities are listed and defined in Table 4.1 and Figure 4.3. The vital capacity, tidal volume, expiratory reserve volume and the inspiratory reserve volume will be measured for this laboratory. In addition, minute volume ($\dot{V}_R$) will also be measured but application will not be made until Laboratory 5, Exercise Metabolism.

Volume versus workload. The volume of air exchanged in response to an increase in workload is controlled by a number of factors:

1. CO_2 - increased cellular activity uses more energy and therefore produces more CO_2. (see Laboratory 5) The CO_2

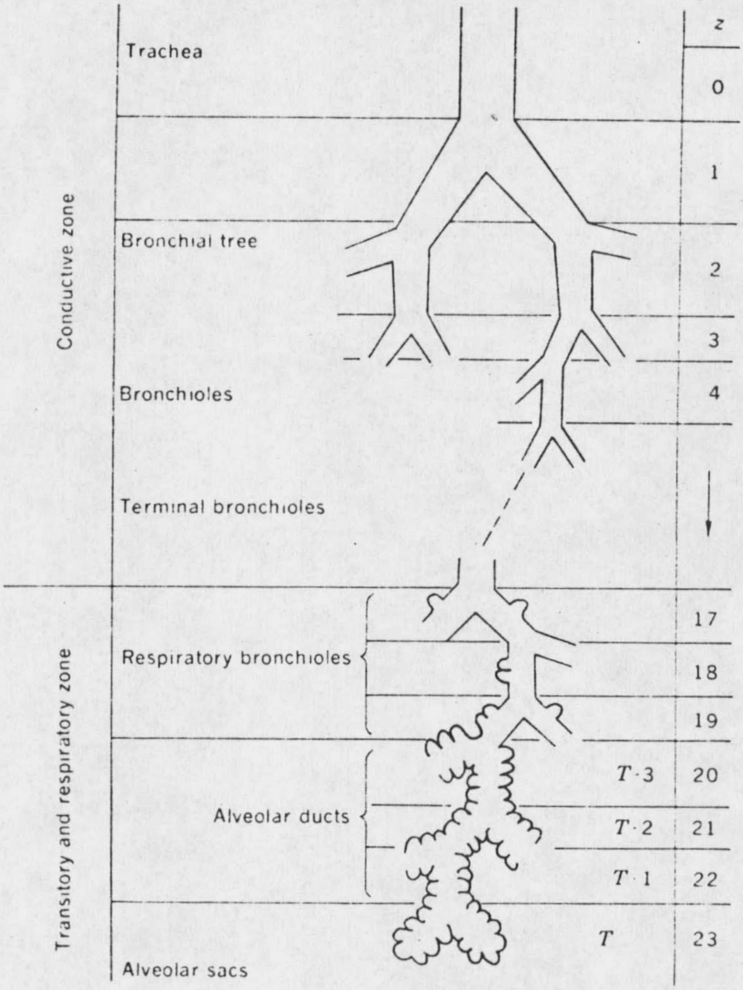


Figure 4.1

ORDER OF SUBDIVISION OF THE GENERAL ARCHITECTURE OF AIRWAY TUBES WITHIN THE LUNGS[5]

5. Åstrand, Per-Olof and Kaare Rodahl, Textbook of Work Physiology, McGraw-Hill Book Company, New York, New York. 1977.

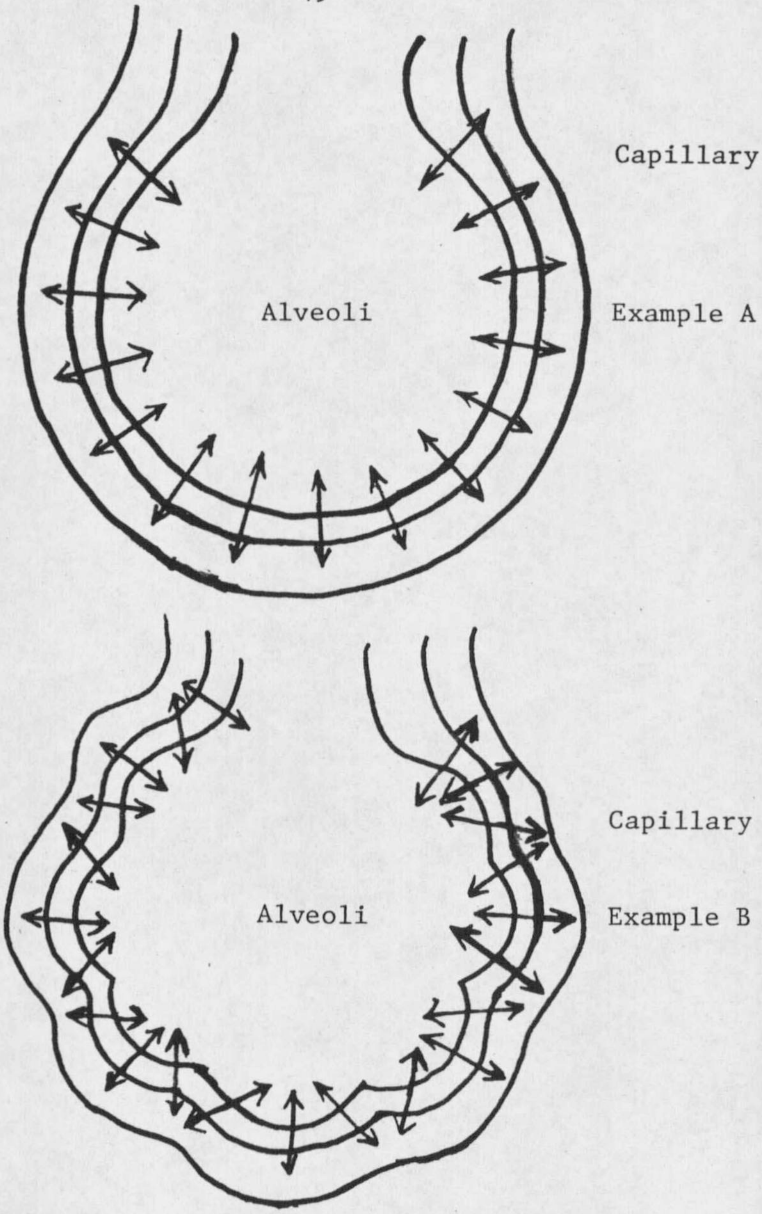


Figure 4.2

ALVEOLI SURFACE AREA EXPOSURE AND GAS EXCHANGE

Example A shows gas exchange between alveoli and capillary. Example B shows increased gas exchange due to larger surface area exposed. Note: ⟷ indicates two-way gas exchange.

Table 4.1

LUNG VOLUMES AND CAPACITIES[15]

A. Volumes. There are four primary volumes which do not overlap.

1. Tidal volume, or the depth of breathing, is the volume of gas inspired or expired during each respiratory cycle.

2. Inspiratory reserve volume is the maximal amount of gas that can be inspired from the end inspiratory position.

3. Expiratory reserve volume is the maximal volume of gas that can be expired from the end expiratory level.

4. Residual volume is the volume of gas remaining in the lungs at the end of a maximal expiration.

B. Capacities. There are four capacities, each of which includes two or more of the primary volumes.

1. Total lung capacity is the amount of gas contained in the lung at the end of a maximal inspiration.

2. Vital capacity is the maximal volume of gas that can be expelled from the lungs by forceful effort following a maximal inspiration.

3. Inspiratory capacity is the maximal volume of gas that can be inspired from the resting expiratory level.

4. Functional residual capacity is the volume of gas remaining in the lungs at the resting expiratory level. The resting and expiratory position is used here as a baseline because it varies less than the end inspiratory position.

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15. deVries, Herbert A., Physiology of Exercise, Wm. C. Brown Company Publishers, Dubuque, Iowa. 1980.