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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by

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

of

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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.

<u>The effect of heat and humidity on physical performance</u>. 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.

<u>Nutritional inventory</u>. 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 x 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

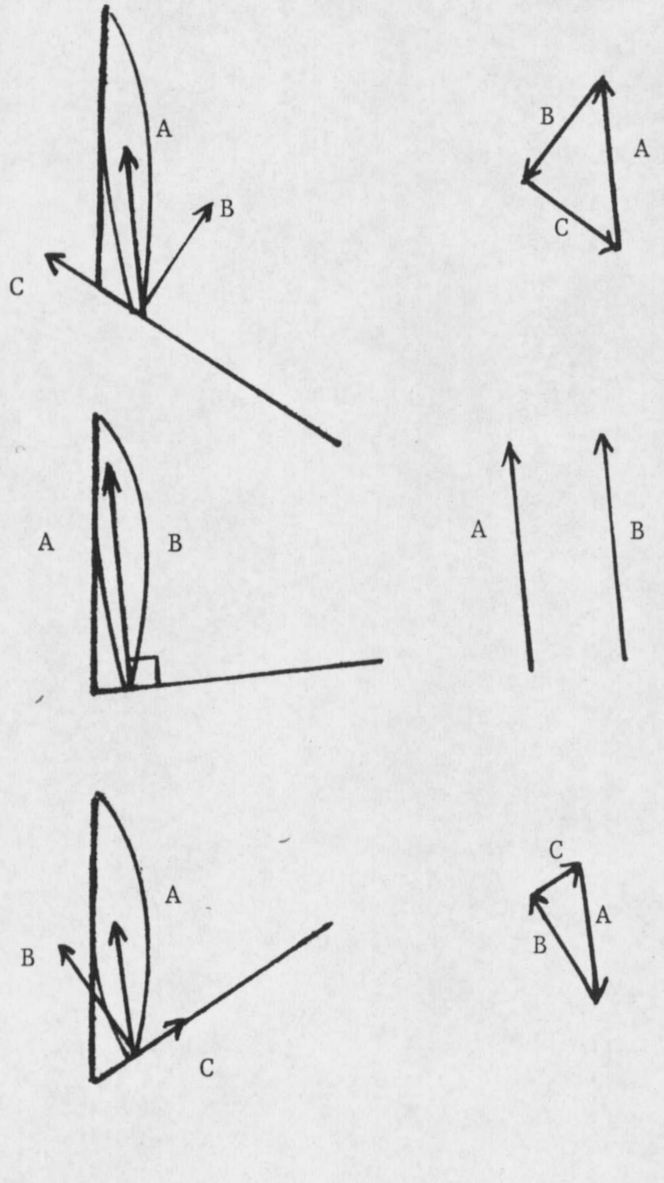

Figure 1.1

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,