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Exercise Physiology

Laboratory Manual

William C. Beam
Gene M. Adams

Mc Graw Hill Education

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Eighth Edition

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Published by McGraw-Hill Education, 2 Penn Plaza, New York, NY 10121.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 QVS 21 20 19 18

ISBN 978-1-260-08555-6
MHID 1-260-08555-4

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PREFACE

The eighth edition of *Exercise Physiology Laboratory Manual* is a comprehensive source of information for instructors and students interested in practical laboratory experiences related to the field of exercise physiology. The manual provides instruction on the measurement and evaluation of muscular strength, anaerobic fitness, aerobic fitness, cardiovascular function, respiratory function, flexibility, and body composition. Each chapter, written in a research format, provides the rationale underlying the test to be completed, includes detailed methods and up-to-date comparative data, and concludes with a discussion of the results based on published studies. *Homework* forms at the end of each chapter can be completed in preview of an upcoming lab or in review of a completed lab. *Lab Results* forms direct students on the collection of laboratory data and the calculation and evaluation of results. *Exercise Physiology Laboratory Manual* can be used as a stand-alone lab manual for a separate exercise physiology laboratory course. It can also serve, however, as a complement to any exercise physiology textbook to provide direction for laboratory experiences associated with an exercise physiology lecture course. And finally, it is an excellent reference source for a variety of other kinesiology courses, including those involved in measurement and evaluation, strength and conditioning, and exercise testing and prescription. The laboratory and field test experiences in this laboratory manual are designed to reinforce the basic principles learned in the lecture and laboratory course and to teach the fundamental skills of measurement and evaluation in the field of exercise physiology. Although specific equipment is described in the laboratory manual, the methods for each test are written as generically as possible, so that differing equipment and instrumentation can be used to conduct the tests. Much of the equipment used today in an exercise physiology laboratory is highly automated and provides instant results at the touch of a button. *Exercise Physiology Laboratory Manual* takes a more “old school” approach, assuming that more learning occurs when students are required to collect the raw data and conduct many of the calculations necessary to derive the final test results.

The Eighth Edition

The eighth edition of *Exercise Physiology Laboratory Manual* remains faithful to the roots established in the previous seven editions over the last three decades. Readers of the manual will find that many hallmarks of the previous editions remain. Numerous changes have been made to the content in the eighth edition, however, and many up-to-date references have been added.

Features of the seventh edition remaining include:

- Written in a research format, the manual includes the rationale behind each laboratory test, detailed methods, comparative data, and a discussion of the results based on published studies.
- Accepted terminology and units of measure are used consistently throughout the manual.
- *Homework* forms are written to emphasize the content of the chapter. They can be completed prior to the lab as a preview of material or can be done following the lab as a review of material.
- *Laboratory Results* forms are written to provide direction in the measurement and evaluation of laboratory data.
- *Accuracy Boxes* appear throughout the manual for those who want to examine the reliability, validity, and objectivity of the tests performed.
- *Calibration Boxes* appear throughout the manual for those who want to go into further depth with the instruments.
- *Chapter Preview/Review boxes* in each chapter include questions to be answered by students either in preview of an upcoming lab or in review of a completed lab emphasize the chapter content and place more responsibility for learning on the students.

Significant changes made to the eighth edition include the following:

- Text changes made throughout the manual intended to make the manual more readable and understandable to students.
- Revised and new text in introduction, methods, and discussion sections throughout the manual to better describe the rationale of the tests, methodology of data collection, and significance of the results. Specific changes include new introductory material in Chapters 18, 23, and 25; changes to the methods sections of Chapters 6 and 18; and newly written discussion sections in Chapters 9, 10, 11, 16, 19, 20, 22, 24, and 26.
- Updated and newly added references to original research studies and other sources of information throughout the manual, especially in Chapters 3, 6, 9, 11, 16, 18, 20, 22, 23, 24, and 26.
- Updated data in numerous chapters, especially height and weight data in Chapter 3, isokinetic strength data in Chapter 6, sprinting data in Chapter 7, new data for categorizing resting blood pressure in Chapter 16, new overweight and obesity data in Chapter 23, new waist girth data in Chapter 24, and new body composition data on college athletes in Chapter 26.
- Changes to numerous tables throughout the manual to make them more "user-friendly," especially tables in Chapters 3, 6, 7, 9, 10, 11, 23, and 26.
- Revisions, some small and some larger, to every *Homework* and *Lab Results* form throughout the entire lab manual.
- Other specific changes include the addition of height and weight data for Asian Americans in Chapter 3; an update of the isokinetic strength methods to match the HUMAC isokinetic dynamometer in Chapter 6; the addition of sprinting data for collegiate athletes in Chapter 7; the addition of a discussion on the measurement of anaerobic fitness in ice hockey players in Chapter 9; the addition of the Maximal Anaerobic Running Test (MART) and expanded discussion on sprint training in Chapter 11; an update to the new 2017 ACC/AHA blood pressure clinical guidelines in Chapter 16; an expanded discussion of estimating oxygen uptake from cycle or treadmill exercise during

the Exercise ECG Test in Chapter 19; the addition of a discussion of the use of lower limit of normal (LLN) in assessing lung function in Chapter 20; and an expanded discussion of the use of waist girth and waist-to-height ratio in assessing risk of chronic disease in Chapter 24.

Content and Organization

The material contained in *Exercise Physiology Laboratory Manual* is divided into eight parts, each of which describes a different type of physiological test or response. Part I, Orientation to Measurement in Exercise Physiology, includes chapters that introduce topics, terminology, variables (e.g., force, work, power), and units of measure (e.g., N, N·m, W) and describe the collection of basic data. Part II, Muscular Strength, includes chapters on the measurement of isotonic, isometric, and isokinetic strength. Emphasis is placed on testing and describing strength in both absolute and relative terms. Part III, Anaerobic Fitness, includes chapters on sprinting, jumping, and anaerobic cycling, stepping, and treadmill running. Numerous modes of testing are described so that the instructor or student can choose the most appropriate test to use based on the specific sport or activity of interest. Before administering any of these tests that require a high degree of physical effort, instructors should consider the health history of the participants (students). Participants (students) completing these tests should be free of disease (i.e., cardiovascular, pulmonary, metabolic); should have no signs or symptoms suggestive of disease (e.g., angina, shortness of breath, irregular heartbeat, dizziness, etc.); and should have few major risk factors for cardiovascular disease (i.e., cigarette smoking, hypertension, hyperlipidemia, diabetes, physical inactivity, obesity, and family history of disease). Appendix A and Appendix B include material that can be used to assess exercise risk.

Part IV, Aerobic Fitness, includes chapters on aerobic walking, jogging, running, stepping, and cycling and on the direct measurement of maximal oxygen consumption ($V{\cdot}O_2max$). This part emphasizes the value of directly measuring $V{\cdot}O_2max$ and why $V{\cdot}O_2max$ is considered to be the one best laboratory test reflecting overall aerobic fitness. The health history of the participants should again be considered before performing any of these tests. Numerous modes of testing are described (e.g., walking, running, stepping), but the instructor may choose not to include all tests from every part.

Part V, Cardiovascular Function, includes chapters on resting and exercise blood pressure and on the resting and exercise electrocardiogram. Part VI, Respiratory Function, includes chapters on resting lung volumes and exercise ventilation. Emphasis is placed on the measurement of lung function and identification of any restrictive or obstructive lung conditions the participant may possess at rest or during exercise. Part VII, Flexibility, includes a description and discussion of the measurement of lower body flexibility. Part VIII, Body Composition, includes chapters on assessing body composition by means of body mass index, girth, skinfolds, and hydrostatic weighing.

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This edition is available online with Connect, McGraw-Hill Education's integrated assignment and assessment platform. Connect also offers SmartBook for the new edition, which is the first adaptive reading experience proven to improve grades and help students study more effectively. All of the title's website and ancillary content is also available through Connect. This includes a ***full test bank*** of questions that test students on central concepts in each chapter, ***lecture slides*** for instructor use in class, and files available online to instructors for every chapter that assist in the instruction of a laboratory course.

The ***Interactive Homework and Lab Results Files*** include an Excel™ file for each chapter. Each file consists of 4 worksheets. Sheet 1 is the blank version of the *Homework* form for that chapter, formatted to fit a standard 8½" × 11" page when printed. Sheet 2 is the completed version with all calculations completed and fitness categories identified. The completed *Homework* form is convenient for grading student work. Sheet 3 is the blank version of the *Lab Results* form for that chapter. Sheet 4 is an "interactive" version of the form that can be used by the instructor to calculate results and identify fitness categories for any desired raw data. Simply insert any raw data into the highlighted areas and all calculations are performed automatically.

The ***Instructional Files*** include an Excel™ file for each chapter. The *Instructional Files* provide background information, rationale behind the use of the test in assessing fitness, and step-by-step instructions for completing the calculations. Each *Instructional File* consists of multiple worksheets. Sheet 1 is the blank *Homework* form for that chapter. The subsequent worksheets provide step-by-step instructions regarding the calculations to help students understand the context of the calculations and results. The file can be projected during class to facilitate discussion of the fitness component being assessed. The final sheet is the completed *Homework* form.

The ***Interactive Group Data Files*** include an Excel™ file for each chapter. These files allow for collection and display of data collected on the entire class. Sheet 1 is a blank *Group Data* sheet that can be used to manually record data. Sheet 2 is an "interactive" version that can be used by the instructor to enter raw data for each student in the class. Simply enter new raw data into the highlighted cells and the file automatically calculates all results and identifies the corresponding fitness categories. The results can be projected for use during class and can be used by the instructor for grading student lab work. Sheet 3 is a sample data file that can be used for various purposes.

Philosophical Approach

Our philosophical approach to learning laboratory procedures is consistent with the following quote:

> A learner does not act without thinking and feeling, or think without acting and feeling, or feel without acting or thinking.[1]

To us, this means that teachers encourage students to be *active* during the laboratory session and not only administer the test but *feel* what it is like to be tested. Then teachers encourage students to *think* about their actions and feelings, so students can truly *know* the material.

Acknowledgments

Every author must acknowledge that the knowledge, ability, motivation, and inspiration to write a work like this laboratory manual comes from many sources. It comes from former teachers, role models, colleagues, students, and family members. We are both especially appreciative of the students in our lab classes. We would like to acknowledge that the enthusiasm our students show in the lab inspires us to continue to teach and write.

From William Beam:

I am grateful to my parents for providing me the opportunity to begin my education at the College of Wooster, a small liberal arts college in my home state of Ohio. The basic science education I received in biology, chemistry, math, and physics prepared me well for graduate study. I took my first exercise physiology course from Dr. Edward Fox at The Ohio State University and it was during this course that I first got a sense of what I really wanted to do professionally. I am grateful also to my other graduate exercise physiology professors, including Dr. Robert Bartels and Dr. Timothy Kirby. I am especially grateful to my friend of 35 years and colleague of 26 years at Cal State Fullerton, Dr. Gene Adams. He provided me the opportunity to coauthor this manual, facilitated my involvement in the Southwest Chapter of the ACSM, and has simply been a wonderful friend and colleague. Thanks also go to my family including my wife, Terri, my son, Dan, and my daughter, Sara. I dedicate this book to each one of them and the love and support they have shown me over the course of these last four editions.

From Gene Adams:

My first teacher, Dr. Larry Morehouse, introduced me to exercise physiology and set the framework for my future knowledge in this field. My second teacher, Dr. Herbert deVries, contributed to my technical and research skills, while enhancing my knowledge and encouraging my involvement in the

profession. My role model, Dr. Fred Kasch, showed me how to apply what I knew to the general public and to students. I am grateful to my colleagues from all parts of the country who contributed their encouragement and ideas. A big thank you goes to my wife, Janet, the illustrator for this manual, and to my son, Mannie, and my daughter, Shawn, who served as my wife's models.

[1] Barrow, H. M., & McGee, R. (1971). *A practical approach to measurement in physical education* (p. 145). Philadelphia: Lea & Febiger.

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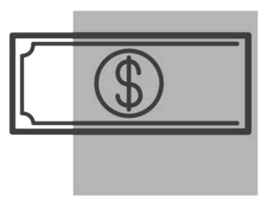

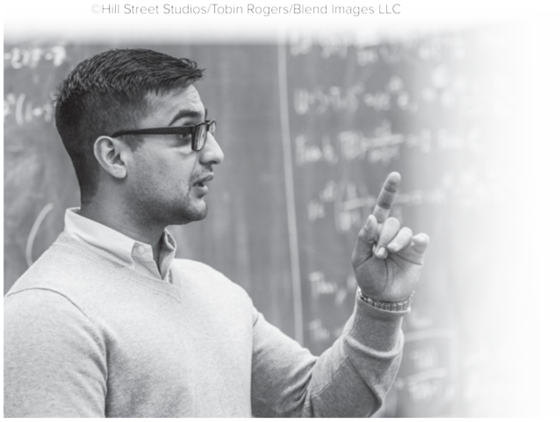

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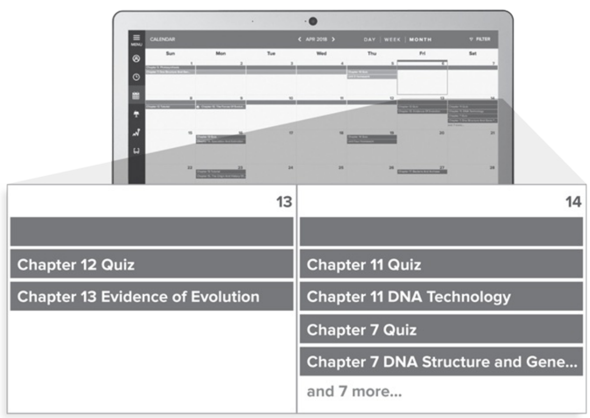

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CHAPTER

1

INTRODUCTION AND TERMINOLOGY

Much of the terminology used to introduce and orient the beginning student to an exercise physiology course may be organized into the following categories: (1) components of fitness, (2) variables of interest, (3) statistical and evaluation terms, and (4) types of tests. Emphasis is placed on those fitness components, variables, terms, and tests that are included in this laboratory manual.

COMPONENTS OF FITNESS

Familiarization with fitness terms is essential for understanding the measurement of physical performance. Performance is often related to a person's fitness. One simple definition of physical fitness is "the ability to carry out physical activities satisfactorily."[16] Because the term *satisfactorily* has many interpretations, it behooves exercise physiologists to describe fitness more precisely in order to make the appropriate fitness measure. One perspective is to view fitness as having various components.[1] Some of the components of fitness include the following:

- Muscular strength and endurance
- Anaerobic fitness
- Aerobic fitness
- Flexibility
- Body composition

These purportedly independent fitness components are directed not only at exercise performance but also at diseases (e.g., cardiovascular) or functional disabilities (e.g., obesity, musculoskeletal pain) associated with hypokinetic (low activity) lifestyles.

Muscular Strength and Endurance

Muscular strength may be defined as the maximal force generated in one repetition at a given velocity of exercise. Strength is necessary for many functional tasks and activities of daily living across the life span. It is required for normal walking and running gait, climbing stairs, rising from a lying or seated position, and lifting and carrying objects. Strength is also an important contributor to higher intensity tasks associated with recreational and sporting events requiring sprinting, jumping, and throwing.

Strength tests included in this laboratory manual emphasize the measurement of one repetition maximum (1 RM), or the maximum amount of weight lifted or force generated in a single repetition. The modes of measurement described involve various muscle actions, including isotonic, isometric, and isokinetic actions (Chapters 4 through 6).

Muscular endurance is a function of the muscle producing force over multiple consecutive contractions and can be assessed in time frames ranging from seconds, to minutes, to hours. Typical tests specifically geared to measure muscular endurance include timed push-ups and sit-ups; completing as many repetitions as possible of a specific load or weight (e.g., 15 lb dumbbell) or physical task (e.g., standing from a chair); or measuring the decline in peak torque over multiple repetitions with an isokinetic dynamometer. No specific tests of muscular endurance are included in this laboratory manual, but muscular endurance is a necessary fitness component for numerous tests, including tests of anaerobic fitness (Chapters 7 through 11) and aerobic fitness (Chapters 12 through 15).

Anaerobic Fitness

From a bioenergetic point of view, exercise and fitness may be categorized based upon the predominant metabolic pathways for producing adenosine triphosphate (ATP). The two anaerobic systems (the **phosphagen system** and the **glycolytic system**) produce ATP at high rates, but in relatively small amounts. Aerobic metabolism (or the aerobic system) produces ATP at a considerably lower rate but in essentially unlimited amounts.

The phosphagen system predominates for strength and power movements requiring anaerobic power and immediate maximal efforts of several seconds (<15 s).[9] The force of these movements also depends upon the muscle mass and neuromuscular recruitment. The phosphagen system and glycolytic system together contribute substantially to activities requiring a combination of anaerobic power and anaerobic endurance that last approximately 15–30 s. The closer the exercise duration comes to 30 s, the greater the contribution from the glycolytic system.

The glycolytic system dominates for activities requiring anaerobic endurance that last approximately 30–60 s. The phosphagen system adds to the ATP being produced by the glycolytic system for maximally paced activities lasting just over 30 s, whereas the aerobic system contributes a meaningful amount of ATP for maximal effort activities lasting closer to 60 s.[21]

As exercise duration continues to increase, optimally sustained movements lasting between approximately 60 s (1 min) and 120 s (2 min) rely on substantial contributions from both the anaerobic and aerobic pathways. The ATP contribution from each pathway varies above and below 50 % of the total ATP, depending upon the duration. Shorter performances closer to 1 min will receive a greater (> 50 %) anaerobic contribution than longer all-out performances nearing 2 min, when > 50 % of the contribution comes from aerobic metabolism or the aerobic system.[30] These types of activities result in high blood lactate levels indicating the significant involvement of the glycolytic system, along with elevated oxygen uptakes indicating the aerobic contribution to the exercise.

Aerobic Fitness

Aerobic metabolism, or the **aerobic system,** is the predominant pathway for ATP production in optimally paced exercise of duration longer than 3 min. Shorter duration activities from about 3 min to 60 min rely primarily on stored and dietary carbohydrates for ATP production. Longer duration activities, or prolonged exercise, lasting greater than 60 min, rely more on stored fats and dietary carbohydrate and also require more consideration of nutritional and hydration factors for successful performance than do shorter tasks.

Cardiorespiratory endurance depends on the level of **aerobic fitness** of the individual. In fact, the terms are sometimes used interchangeably. Cardiovascular function (including the control of heart rate, blood flow, and blood pressure) plays a fundamental role in the delivery of oxygen to working skeletal muscle. Respiratory function (including the control of breathing rate, tidal volume, and pulmonary ventilation) allows for the appropriate loading and unloading of oxygen and carbon dioxide from the circulating blood during exercise. The greater aerobic fitness an individual possesses, as indicated by the maximal oxygen uptake ($\dot{V}O_2$ max), the higher the cardiorespiratory endurance.

Many performance tests presented in this manual may be categorized based on their reliance on anaerobic or aerobic fitness (Table 1.1). Anaerobic fitness contributes greatly to 1 RM strength tests, sprint tests, vertical jump tests, and anaerobic cycling, stepping, and treadmill tests. And aerobic fitness contributes to numerous performance tests designed to measure cardiorespiratory endurance using walking, jogging, running, stepping, or cycling.

Table 1.1 Fitness Component and Energy System Contributing to Performance Tests Based on Exercise Duration

Exercise Duration	Fitness Component	Energy System Contributing	Performance Test
< 15 s	Anaerobic fitness	Phosphagen system	1 RM tests, Sprint tests, Vertical jump tests

15 to 30 s	Anaerobic fitness	Phosphagen system and Glycolytic system	Wingate test
30 to 60 s	Anaerobic fitness and Aerobic fitness	Glycolytic system and Aerobic system	Anaerobic treadmill test
1 to 3 min	Anaerobic fitness and Aerobic fitness	Glycolytic system and Aerobic system	Anaerobic step test
3 to 60 min	Aerobic fitness	Aerobic system (carbohydrate)	Rockport test, Cooper test, Forestry step test, Astrand cycle test, VO_2max test
> 60 min	Aerobic fitness	Aerobic system (fat)	

Flexibility

Flexibility is typically defined as the ability of a joint to move through its full, functional range of motion permitted by muscle and connective tissues. A lack of flexibility in single joints or in combinations of joints can reduce sport performance, physical function, and in some cases activities of daily living. Many people consider inflexibility a cause of certain athletic injuries (e.g., muscle strains) and a possible contributing factor in low-back pain. Excessive flexibility, however, may also be a problem because it potentially promotes joint laxity or hypermobility, which can lead to joint pathologies. Tests of flexibility are included in Chapter 22.

Body Composition

Body composition refers to the composition of the human body with regard to two primary components: fat tissue and fat-free or lean tissue. Most tests of body composition have as their objective an estimate of percent body fat. Once percent body fat is determined, other body composition variables can be calculated, including fat weight, lean weight, and estimated body weights at various desired percent body fats. Body composition can be assessed using numerous methodologies, including anthropometric measures of girths or skinfolds (Chapters 24 and 25), densitometry by underwater weighing (Chapter 26), bioelectrical impedance, volume displacement, absorptiometry (e.g., DXA), imaging techniques, and more.

There is significant interest in body composition among exercise physiologists and public health experts. Many sports benefit from athletes having low body fat (e.g., distance running, high jumping) or high lean weight (e.g., sprinting, football). Excess body fat and obesity play a role in determining the risk of chronic diseases, including metabolic syndrome, coronary heart disease, and diabetes mellitus.

Variables of Interest

When exercise physiologists measure fitness or exercise performance, they are typically interested in measuring quantities or variables such as mass, length, time, temperature, force, work, power, energy, speed, volume, pressure and more. Seven specific quantities are referred to in the metric system as **base quantities,** meaning they are assumed to be mutually exclusive, each of which is expressed in a **base unit** (included in parentheses). The base quantities used in this manual include length (meter, m), mass (kilogram, kg), time (second, s), and thermodynamic temperature (kelvin, K). The remaining SI base quantities, not used in this lab manual, include electric current (ampere, A), amount of substance (mole, mol), and luminous intensity (candela, cd). All of the other quantities or variables discussed in this lab manual (i.e., force, work, power, energy, volume, etc.) are **derived quantities,** derived from the base quantities through a system of equations, typically using multiplication or division.[32] For example, the base quantity *length* (m) can be used to derive *area* (m^2), *volume* (m^3), and in combination with *time* (s) the derived quantities *velocity* ($m \cdot s^{-1}$) and *acceleration* ($m \cdot s^{-2}$). A further discussion of base quantities, derived quantities, and the metric system of measurement is included in Chapter 2.

Mass and Weight

Mass is a base quantity defined as the quantity of matter in an object. Under the normal acceleration of gravity ($9.81 m\cdot s^{-2}$), mass is equivalent to **weight.** So generally, as long as we assume the effect of gravity is constant over the entire surface of the earth, we can assume that *mass* and *weight* are equal and the terms can be used interchangeably. However, should we travel to the moon (where the acceleration of gravity is 1/6 that of earth, or $1.62\ m\cdot s^{-2}$), the weight of the object would be less. A person on earth with a body mass of 70.0 kg also has a body weight of 70.0 kg. On the moon, this same person still has a *body mass* of 70.0 kg, but has a *body weight* of only 11.6 kg, due to the reduced effect of gravity.

Length and Height

Length is the measure of how long an object is, most frequently from end to end. The length of an American football field from end to end is 100 yd; the length of a yardstick is 36 in. **Height** is also a measure of how long an object is, but is typically applied to the *vertical length* of an object from the ground. Typically, a person is described as having a height of 70 in. or 178 cm, instead of being 70 in. or 178 cm long. A mountain peak is described as being 4000 m high. It is interesting to note, however, in describing newborn babies, the term *length* is used instead of *height* because they cannot stand and therefore as traditionally viewed have no *vertical length,* or height.

Distance and Displacement

Distance and **displacement** are frequently interchanged and used to express the same variable. However, they are two distinct and separate terms expressing potentially different lengths. *Distance* is the total sum of the length of the path traveled by the exerciser. *Displacement,* on the other hand, is determined taking into account the starting and ending points of the exerciser. Displacement is literally the length of the straight-line path between the starting and ending points of the exerciser. As an example of the difference between distance and displacement consider a baseball player who hits an "inside-the-park home run." The *distance* run by the player is the sum of the length of the path traveled, or *360 ft* (knowing that each of the four bases is 90 ft apart). The *displacement* of the player, however, being the length of the straight-line path between the starting and ending points, is *0 ft* because the starting and ending points are the same point, home plate.

Force

Force is a derived quantity calculated as the product of mass and acceleration. It is defined as that which changes or tends to change the state of rest or motion in matter.[3] Thus, muscular activity generates force. Mass and force are two basic quantities that are similar under certain circumstances. For example, there are times when you will use your body weight (mass) as a measure of force in order to calculate your work load or work rate. A person applying a maximal force to a resistance or load, whether against gravity or a lever, is displaying the fitness component of strength. Most muscular activity, however, uses submaximal forces.

Work

Work is derived from the product of two basic quantities: force and length (distance or displacement). Mechanical work is the product of the force applied against an object and the distance the object moves in the direction of the force while the force is applied to the object. Mathematically, work is the product of the force (F) applied, the angle (θ) at which the force is applied on the object, and the distance (D) the object is moved. When the force is applied parallel to the line of displacement (or at an angle of 0°), the equation simplifies to Eq. 1.1. Often in exercise physiology, the amount of work done during a particular activity is of interest, such as stepping up and down on a bench, walking or running on a treadmill, or pedaling a cycle ergometer. In these cases, work is calculated based on body mass, step height and frequency, treadmill speed and grade, the cycle speed and resistance, and the total exercise time.

$$\text{Work (W)} = \text{Force (F)} * \text{Distance (D)} \qquad \text{Eq. 1.1}$$

Power

Power is the variable that expresses the rate of work done. Mathematically, power is calculated as work divided by time, as in Eq. 1.2. A more powerful exercise is one in which there is either a larger amount of work done in a given time, or there is a given amount of work done in a shorter time. Power is a term often used when referring to the rate of transforming metabolic energy to physical performance, such as aerobic power and anaerobic power. However, instead of viewing these metabolic terms as power terms, as would a physicist, the exercise physiologist would typically view them as energy terms.

$$\text{Power (P)} = \text{Work (W)} / \text{Time } (t) \qquad \text{Eq. 1.2}$$

Energy

Energy is often simply defined as the ability to do work. Energy more specifically describes the amount of metabolic energy released due to the combination of mechanical work and the heat of the body itself. Energy expenditure during exercise can be measured using either direct or indirect calorimetry. Direct calorimetry is a complicated and expensive process of measuring metabolic rate by directly measuring heat production. Indirect calorimetry is based on measuring the exerciser’s oxygen uptake, assuming that oxygen consumed is related to the amount of heat produced in the body during exercise. An oxygen uptake of 1 $L{\cdot}min^{-1}$ is assumed to have a caloric equivalent of approximately 5 $kcal{\cdot}L^{-1}$, or 21.1 $kJ{\cdot}L^{-1}$. This allows for the estimation of energy expenditure at rest and during exercise in kcal or kJ. By