7TH EDITION

# EXERCISE PHYSIOLOGY

## *Laboratory Manual*

WILLIAM C. BEAM • GENE M. ADAMS

Seventh Edition

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## LABORATORY MANUAL

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# PREFACE

The seventh 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 Seventh Edition

The seventh edition of *Exercise Physiology Laboratory Manual* remains faithful to the roots established in the previous six 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 seventh edition, however, and many up-to-date references have been added.

Features of the sixth 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 seventh edition include:

- 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 20, 21 and 23; changes to the methods sections of Chapters 8, 9, 13, 17 and 23; and newly written discussion sections in Chapters 8, 10, 11, 17, 20 and 23.
- Updated and newly added references to original research studies and other sources of information throughout the manual, especially in Chapters 1, 2, 3, 6, 8, 9, 13, 15, 19, 20, 23 and 24.
- Updated comparative data in numerous chapters, especially height and weight data in Chapter 3, comparative anaerobic fitness data in Chapter 10, comparative aerobic fitness data in Chapter 13, and additional lung function data in Chapter 20.
- Changes to numerous tables throughout the manual to make them more "user-friendly," especially tables in Chapters 3, 4, 6, 13, 14, 15 and 25.
- Changes to numerous *Chapter Preview/Review* boxes throughout the manual, especially in Chapters 4, 6, 7, 8, 9, 10, 22 and 24.
- Changes to *Homework* and *Lab Results* forms throughout the manual, especially in Chapters 10, 13, 14, 17 and 22.
- Other significant changes include the addition of alternate aerobic fitness tests in Chapters 13 and 14; changes in tables, figures and discussion in Chapter 17 related to rate-pressure product; addition of lung function comparative data for Asian-Americans in Chapter 20; addition of goniometry in Chapter 22; changes to methods and discussion in Chapter 23; and addition of waist-to-height ratio 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 ($\dot{V}O_2max$). This part emphasizes the value of directly measuring $\dot{V}O_2max$ and why $\dot{V}O_2max$ 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, include 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.

## Homework and Lab Results Files on McGraw-Hill Online Learning Center Website

Files for every chapter in ***Exercise Physiology Laboratory Manual, 7e***, are posted on the McGraw-Hill Online Learning Center website. The files are intended to assist in the instruction of a laboratory course. They can be projected for use during class and can be used by the instructor to grade homework forms and evaluate lab results.

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 sheets 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 in 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 over the values printed in blue 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.

## Custom Version Available

To meet the needs of your specific course, you can create a customized version of *Exercise Physiology: Laboratory Manual* through McGraw-Hill Primis Custom Publishing. You can select the chapters you want, rearrange chapters, and personalize the manual by adding your own original content, including your own equipment list. Your customized content can be delivered to your students either electronically or as a print product. For more information, visit www.primisonline.com or contact your local McGraw-Hill sales representative.

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

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### *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 colleague of 23 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 colleague and friend. 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 3 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.

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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. 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.

## 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.

**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, $VO_2$max test |
| > 60 min | Aerobic fitness | Aerobic system (fat) | |

## 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.

Power (P) = Work (W) / Time ($t$) 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 22 $kJ \cdot L^{-1}$. This allows for the estimation of energy expenditure at rest and during exercise in kcal or kJ. By expressing oxygen uptake as a rate in $L \cdot min^{-1}$, a rate of energy expenditure in $kcal \cdot min^{-1}$ (Eq. 1.3a) or in $kJ \cdot min^{-1}$ (Eq. 1.3b), the preferred metric unit, can also be derived.

Energy ($kcal \cdot min^{-1}$) = Oxygen uptake ($L \cdot min^{-1}$) * 5 $kcal \cdot L^{-1}$ Eq. 1.3a

Energy ($kJ \cdot min^{-1}$) = Oxygen uptake ($L \cdot min^{-1}$) * 22 $kJ \cdot L^{-1}$ Eq. 1.3b

## Speed and Velocity

**Speed** is the quotient of distance (D) divided by time ($t$), where distance represents the actual length covered (Eq. 1.4a). **Velocity** is calculated as displacement (d) divided by time ($t$), where displacement represents the straight-line distance between a specific starting point and ending point (Eq. 1.4b). In many instances, the term speed is substituted for velocity, but mechanically speaking, speed and velocity are different.[17] For example, a track athlete who runs 1 lap of a 400 m track in 50 s is running at a *speed* of 8 $m \cdot s^{-1}$ (400 m / 50 s). Technically, however, because the athlete starts and ends at the same point, the displacement is 0 m and therefore the *velocity* is 0 $m \cdot s^{-1}$ (0 m / 50 s).

Speed = Distance (D) / Time ($t$) Eq. 1.4a

Velocity = Displacement (d) / Time ($t$) Eq. 1.4b

## Angular Velocity

The two variables just described, speed and velocity, are measured linearly (in a straight line). **Angular velocity** describes the velocity at which an object rotates or spins. It can be described in degrees per second ($deg \cdot s^{-1}$) as is frequently the case in isokinetic dynamometry (Chapter 6). The preferred SI unit, however, for expressing angular velocity is $radians \cdot second^{-1}$. There are $2\pi$ radians in a complete circle, so one radian is about 57.3°

## Torque and Peak Torque

**Torque** is a force or combination of forces that produces or tends to produce a rotating or twisting motion. Torque is used to describe muscular strength measurements taken with an isokinetic dynamometer (Chapter 6). It is mathematically the product of the linear force (F) applied to the device and the perpendicular length (D) of the lever arm at which that force is applied (Eq. 1.5). **Peak torque** is typically described as the greatest torque produced over several trials and is used as a measure of muscular strength.

Torque ($\tau$) = Force (F) * Lever arm length (D) Eq. 1.5

## Volume

Several different measurements of **volume** are of interest in this manual with regard to the lungs, including static lung volumes (e.g., inspiratory reserve volume), lung function volumes (e.g., forced expiratory volume), and volumes and rates of exhaled air (e.g., pulmonary ventilation). Lung volumes, lung function, and exercise ventilation are discussed in Chapters 20 and 21. Each of these volumes is affected by changes in temperature and pressure, which vary between ambient (surrounding) conditions, body conditions, and standard conditions. *Body volume* is of interest due to its involvement in the determination of body density and percent body fat (Chapter 26). The measurement of *fluid volume* is also an important consideration in the exercise physiology lab.

## Pressure

**Pressure** is exerted in different ways and expressed in a variety of units. Gases and liquids exert pressure on the walls of the containers in which they are held. *Blood pressure* is the pressure exerted by the circulating blood on the walls of the blood vessels, with most interest being in arterial blood pressure and its measurement at rest and during exercise (Chapters 16 and 17). *Barometric pressure* refers to the air pressure of the environment. Altitudes can be estimated from air pressures, and weather patterns can be dictated by changes in air pressures. Normal exercise responses occur at barometric pressures common near sea level (760 mm Hg). However, aerobic power is usually less at barometric pressures associated with altitudes above 1500 m (4920 ft).[10] Barometric pressures are used to correct respiratory ventilation volumes and metabolic volumes.

### Temperature

Temperature is a measure of the hotness or coldness of any object and can be expressed on any one of three scales. Americans are familiar with the Fahrenheit scale, but the two most common scales for scientists are the Celsius scale and the scale using kelvin units. Usually, the Fahrenheit scale is not printed in scientific research journals, although sometimes it is presented in parentheses after the Celsius degree.

#### *Celsius Scale*

Celsius, formerly called the centigrade scale, is named for Anders Celsius, a Swedish mathematician. He created the centigrade scale by arbitrarily dividing the difference between the freezing point and boiling point of water into 100 equal degrees (0 °C and 100 °C, respectively). The appropriate term now in use for this scale is Celsius.[4]

#### *Kelvin Scale*

The basic thermal SI unit is the kelvin, named after 19th-century physicist William Kelvin. It has an absolute zero, meaning that the coldest possible temperature truly is zero kelvin (0 K), and there is no *minus* or *below zero* temperature for this scale. Because a kelvin unit is equal in size to a Celsius degree, absolute zero (0 K) corresponds to −273°C. Or conversely, 0 °C is equal to 273 K. To convert temperature between the two scales, one need only add or subtract 273. Notice that the *k* in kelvin is not capitalized, but the abbreviated symbol K is.

#### *Fahrenheit Scale*

Gabriel Fahrenheit, in developing the Fahrenheit scale, arbitrarily chose the number 32 to designate the melting point of ice and 96 as the temperature of human blood. Although this temperature scale accommodates most of earth's weather situations, it is not as convenient for calculations as the Celsius and kelvin scales. Thus, SI[30] does not recommend its use as a measurement scale.

## Statistical and Evaluation Terms

The term *statistics* can have more than one meaning.[22] In a broad sense, it includes the method of organizing, describing, and analyzing quantitative (numerical) data, in addition to predicting outcomes or probabilities. The combined term *basic statistics* is sometimes used to describe group data with such statistics as the mean (*M*) and standard deviation (*SD*).

### Independent and Dependent Variables

A **variable** is a characteristic. The characteristics, or variables, mentioned in this laboratory manual usually have quantitative values that vary among the members of a sample or population. Some of the measured variables discussed in this manual are strength, run/walk time, oxygen consumption, heart rate, blood pressure, and percent body fat. A variable is either independent or dependent.

An **independent variable** is manipulated, or changed, in order to determine its relationship to the dependent variable.[32] The independent variable's measuring unit is usually placed on the horizontal (X) axis of a graph. It is used to predict or estimate the dependent variable, as in using skinfold thickness (independent variable) to estimate percent body fat (dependent variable). The experimenter or technician controls the independent variable.[20]

A **dependent variable** is measured before and/or after manipulation of the independent variable. Its measuring unit is usually placed on the vertical (Y) axis of a graph. The dependent variable is predicted or estimated from the independent variable, as in estimating maximum oxygen uptake (dependent variable) from walking or running distance (independent variable) as seen in Figure 1.1.

### Correlation and Prediction

**Correlation** analysis involves the observation of relationships between variables by plotting the data on a graph and calculating a correlation coefficient (*r* or *R*) The closer the points come to forming a straight line, the higher the correlation or the stronger the relationship between the two variables. The value of *r* can range from −1.00 to + 1.00, with the sign indicating the direction of the relationship (direct or inverse) and the value indicating the strength of the relationship. A positive *r* indicates a positive (direct) relationship between two variables, where an increase in one variable is associated with an increase in the other variable. A negative *r* indicates a negative (inverse) relationship between two variables, where an increase in one variable is associated with a decrease in the other variable. An *r* of 0.00 indicates no relationship between two variables; an *r* of 1.00 indicates a perfect, direct relationship between two variables; and an *r* of −1.00 indicates a perfect, inverse relationship. Figure 1.1 shows data from Chapter 14 demonstrating the strong, direct relationship (as indicated by the *r* of 0.91) between distance run/walked in 12 min and maximal oxygen uptake. An increase in distance run/walked is closely associated with an increase in maximal oxygen uptake.

#### *Reliability, Validity, and Objectivity*

A good test of body composition, aerobic fitness, or any other measure of physical performance should be reliable, valid, and objective. Each of these test characteristics can be described and assessed statistically using correlation analysis, as seen in Figure 1.2.

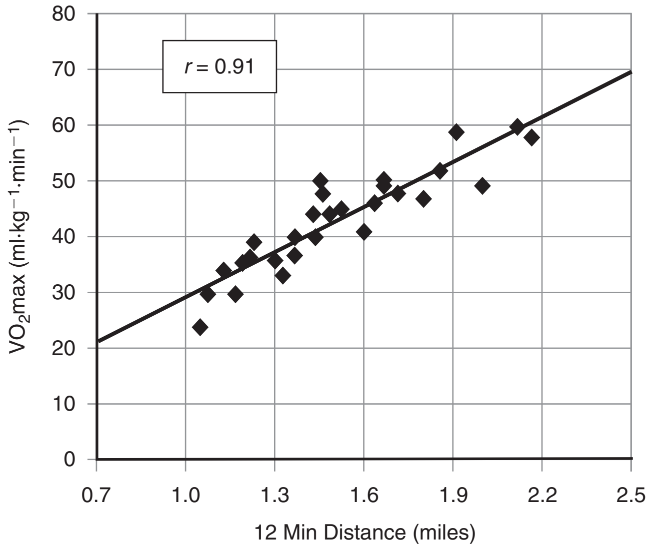


**Figure 1.1** Data from Chapter 14 demonstrating the linear relationship between distance run/walked in 12 min and maximal oxygen uptake. The high, positive correlation coefficient (*r* = 0.91) indicates a strong, direct relationship between the two variables.

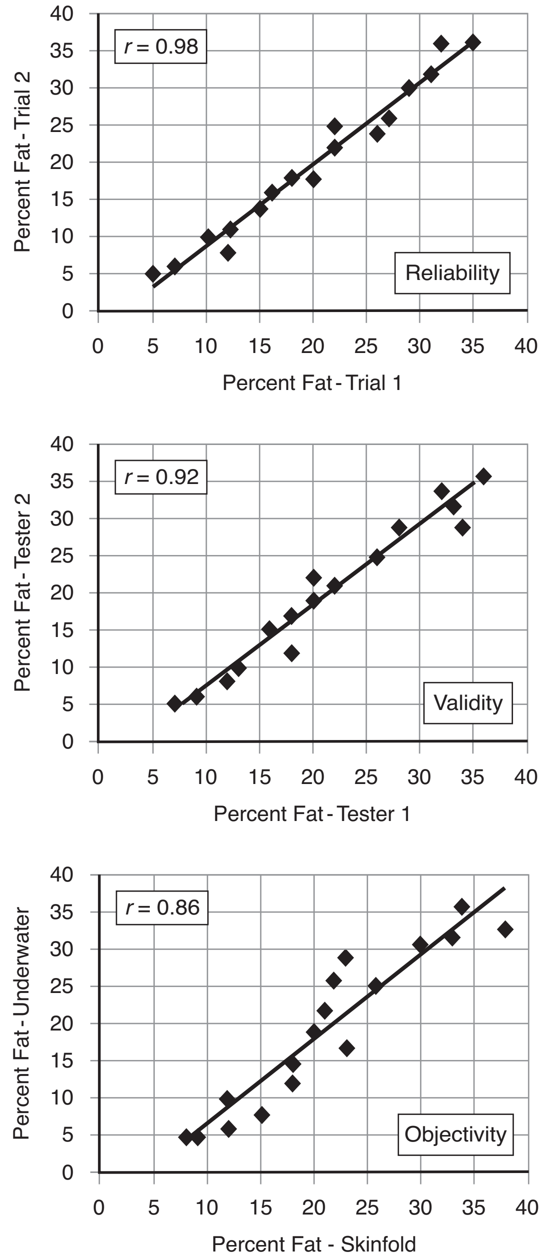


**Figure 1.2** Demonstration of reliability (comparing 2 trials done by the same tester), objectivity (comparing 2 different testers using the same method), and validity (comparing 2 different methods) of measuring percent fat.

**Reliability** is an estimate of the reproducibility or consistency of a test. Reliabilities of tests should be based on a sample of at least 30 participants.[23] A reliable test generates a high intraclass correlation coefficient (*R*) and a high interclass correlation coefficient (*r*) when data from repeated trials of that test are compared. Based on input from other investigators,[8,18,21,26,29] the correlation coefficient criteria that may be used to qualitatively categorize reliability and validity ranging from poor to high are summarized in Table 1.2. The criterion for an acceptable correlation coefficient for reliability may vary with the opinions of various investigators; a recommended minimum test-retest correlation can be as low as .70[25,29] or, more stringently, as high as .85.[18]

The reliability of a test may be affected by the experimental and biological error (variability). Experimental variability is due to lab procedures, instrumentation, and environment; thus, it represents the technical error in a test. Biological variability or error is due to the natural periodicity (hourly, daily, weekly) or inherent biological fluctuations of the human participant.[19]

**Validity** is the ability of a test to measure what it claims to measure. A test with high validity has a good correlation (*r*) with the criterion measure (actual or true). For example, run-walk distances or times are often judged for concurrent validity by their correlation with scores on maximal oxygen uptake tests. The guidelines for qualifying meaningful criterion validity coefficients need not be as high as for those guidelines that qualify reliability coefficients (Table 1.2). For example, correlation coefficients

**Table 1.2 Subjective Criteria for Assessing the Reliability and Validity of a Test**

| Category for Test Reliability | Correlation Coefficient | Category for Test Validity | Correlation Coefficient |
|---|---|---|---|
| High reliability | .90–1.00 | High validity | .80–1.00 |
| Good reliability | .80–.89 | Good validity | .70–.79 |
| Fair reliability | .70–.79 | Fair validity | .60–.69 |
| Poor reliability | < .70 | Poor validity | < .60 |

≥.80 can be interpreted as indicating high test validity; whereas correlation coefficients ≥.90 are required to indicate high test reliability.[29]

Two other types of validity are content validity and construct validity. Content validity relies on expert opinion or past research, and construct validity indicates the test's ability to discriminate among groups.[26] Most validity coefficients described in this laboratory manual are based on concurrent validity.

**Objectivity,** although similar to reliability, is distinct in that it represents the ability of a test to give similar results when administered by different administrators. It is sometimes referred to as *inter-observer reliability* or *inter-rater reliability.* Measuring skinfold thickness to estimate percent body fat, when done by one well-trained tester, typically is highly reliable and valid. If the same degree of reliability and validity is produced from measurements taken by a second tester, the objectivity of measuring skinfold thickness would also be considered high. The goal of any test is for it to be reliable (give the same results twice), valid (measure what it claims to measure), and objective (produce correct results regardless of the tester).

### *Prediction*

The relationship between one variable and one or more other variables allows transformation into an equation to predict or estimate the dependent variable. The line of best fit of the graphic plot of one variable to another is termed a **regression line.** When it is transformed into an equation, it is called a **regression equation.** Sometimes regression equations are presented in the form of a **nomogram,** a series of two or more vertical or diagonal lines by which to predict one variable from one or more other variables without performing any calculations.

The statistical term that describes the predictive error of a regression equation is the **standard error of estimate *(SEE).*** This is a type of standard deviation around the predicted scores from the regression line. For example, if the predicted lean mass is 40 kg, and the *SEE* is 5 kg, then 68 % of the scores will be between 35 kg and 45 kg. Thus, the standard error of the estimate indicates the amount of error to be expected in a predictive score.[6] One researcher suggests an acceptable *SEE* criterion of less than 15 % for aerobic fitness estimation.[13]

## Norms and Standards

Norms and standards enhance the interpretation of test scores. Although the two terms are often used interchangeably, they are different.

### *Norms*

**Norms** are values that relate a person's score to those of the general population. Some authorities suggest that the minimum number of participants to establish norms be set at 100 for each category.[5] If the population sample number is less than 100, or if the samples within a population (e.g., specific age groups) are less than 100, it is probably more appropriate to refer to the data as *comparative scores,* rather than norms. The statistics derived from the norms are often used to develop descriptive categories such as poor, below average, average, above average, and excellent. For example, if a person is categorized as excellent in a certain fitness component on the Canadian Standardization Test and falls at the 85th percentile, then that person ranks better than 85 % of the population.[14] Table 1.3 shows three categorization scales based on percentiles.[14,15,27]

### *Standards*

**Standard** is a term often used synonymously with norms. However, more appropriately, it is used to connote a desirable or recommended value or score.[2] The term *criterion-referenced standards (CRS)* is a professionally popular term.[12,18,24] It has an advantage over normative standards for fitness tests because CRS indicate the levels necessary for good health, regardless of the level of physical fitness of the reference group.[7,11,24,28] The CRS for fitness tests may be based upon professional expertise and scientific research, in addition to normative data.[11] Thus, CRS are standards that represent recommended levels of performance. Because the CRS are absolute standards, they do not consider the number of persons who meet the standard. The CRS levels allow easy recognition of the adequacy or inadequacy of a person on that particular fitness/health variable. Also, as long as a person meets the CRS criterion, he or she has the same merit as someone who scores extremely high on the variable.

Because the criterion standards are based partially on human judgment, and because of testing errors or participant motivation, the cutoff scores may cause false merit or false nonmerit. Also, the merit levels usually do not indicate fitness levels a person may need to be successful

**Table 1.3 Examples of Descriptive Categories Based on Percentiles**

| Test | Percentiles | Category |
|---|---|---|
| Canadian Standardization Test | 81–100 | Excellent |
| | 61–80 | Above average |
| | 41–60 | Average |
| | 21–40 | Below average |
| | 1–20 | Poor |
| Institute for Aerobics Research, YMCA | 90–100 | Well above average |
| | 70–89 | Above average |
| | 50–69 | Average |
| | 30–49 | Below average |
| | 10–29 | Well below average |
| Functional Fitness Test | 76–100 | Above average |
| | 25–75 | Average |
| | 1–24 | Below average |

*Sources:* Based on Fitness and Amateur Sport Canada (1987)[14]; Institute for Aerobics Research, Dallas, TX; Golding, Myers, & Sinning (1989)[15]; Rikli & Jones (1999).[27]

**Table 1.4 Fitness Components and Examples of Their Measurement in Laboratory Tests and Field Tests**

| Fitness Component | Examples of Laboratory Tests | Examples of Field Tests |
|---|---|---|
| Muscular strength and endurance | Peak torque (e.g., isokinetic dynamometry) | 1 Repetition max (RM) test |
| | Peak force (e.g., handgrip dynamometry) | Timed repetitions (e.g., sit-ups) |
| Anaerobic fitness | Peak power (e.g., Wingate test) | Sprint tests (e.g., 40, 50, 60 yd) |
| | | Vertical jump and leg power tests |
| Aerobic fitness and cardiorespiratory endurance | Maximal oxygen uptake test | Walking test (e.g., Rockport test) |
| | | Running test (e.g., Cooper test) |
| Flexibility | Range of motion (e.g., goniometry, electrogoniometry) | Flexibility (e.g., sit and reach) |
| | | Height-weight measures |
| Body composition | Hydrostatic weighing, DXA, plethysmography | Skinfold and girth measures |

in recreational or competitive sports; they are concerned mainly with health-related fitness. Thus, norms describe a person's position within a population, whereas standards describe the criteria suggested for appropriate health-related fitness of a population.

## Types of Tests

The 30 or more tests described in this laboratory manual can be classified as laboratory tests or field tests based on the setting and equipment required, the degree of control maintained during the test, and the application of the results.

### Laboratory Tests

A test is classified as a **laboratory test** when it can only be performed within the confines of the laboratory and requires the testing equipment found within the laboratory (e.g., metabolic measurement system, isokinetic dynamometer). An attempt is made during the test to maintain a high degree of control over many conditions involving the laboratory (e.g., temperature), the participant (e.g., diet, amount of rest, warm-up prior to the test), and the protocol (e.g., time intervals, specific treadmill speeds or cycle ergometer power levels). When the test results are to be used in research, it is common to use a laboratory test. To be useful, research requires test results that are highly reliable and valid, characteristics that should apply to well-conducted laboratory tests.

### Field Tests

It is not always practical or possible to bring the population of interest into the laboratory to conduct the desired tests. Bringing participants into the laboratory frequently requires testing participants individually, providing transportation, arranging for entry into the laboratory (e.g., gaining access to a university campus), and sharing time in the laboratory and on the necessary laboratory equipment with other testers. Conducting the tests in the laboratory under controlled conditions also in some cases creates a contrived or artificial environment that differs from the more desired natural environment and can influence the results of the test. For these and other reasons, testers have developed **field tests** that can be taken to the population of interest and conducted under more natural conditions.

**BOX 1.1 Chapter Preview/Review**

What are the components of fitness?
What are the three energy systems?
How does exercise duration influence the contributions of the energy systems to physical performance?
What are some of the common variables measured in the exercise physiology laboratory?
What are the three scales that can be used to express temperature?
What is a correlation coefficient and what does it indicate about a relationship between variables?
What is meant by the reliability, validity, and objectivity of a test?
What is the difference between a laboratory test and a field test?

Field tests are frequently used to assess a variety of fitness components, including muscular strength, muscular endurance, anaerobic fitness, aerobic fitness, flexibility, and body composition. Field tests in physical education were developed to test large groups of persons outside of a laboratory setting as accurately and economically as possible. Unless extrinsic variables (e.g., weather, terrain, motivation) are strictly controlled, field tests are not as appreciated in research as are the more controlled laboratory tests. This does not mean that field tests cannot be as valid as some laboratory tests. In addition to their use in physical education classes, field tests are popular as screening and maintenance tests for military and safety/ emergency personnel (e.g., firefighters, lifeguards, police, and rangers) and for college or professional sports recruiters. Table 1.4 gives examples of laboratory and field tests.

## Summary

Many of the basic terms used in exercise physiology are summarized in this chapter. As with learning any new language, the beginner should practice using these terms so that they become a natural part of the exercise physiology vocabulary. Students are encouraged to scan through the entire laboratory manual to get an idea of the scope of what is measured in the exercise physiology lab.

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# CHAPTER 2

# *Units of Measure*

*Measuring units* is the term given to describe the type of measure being made. For instance, in the United States we use *pounds* to describe weight and *feet* and *inches* to describe height. The units most commonly used in exercise physiology are those that measure variables associated with exercise, physiology, and meteorology. Some of these were introduced in Chapter 1. In accordance with the International System (SI) of nomenclature, numerous variables are described with such measuring units as kilogram, liter, meter, and kelvin. Many variables combine two or more measuring units to form such units as liters per minute and milliliters per kilogram per minute.

The quantification of exercise physiology requires that all variables have well-defined units of measure. Americans are most familiar with such units as inches, feet, and pounds, which they use in their daily lives. These units are sometimes referred to as *customary units*. However, the single measuring system that is officially approved worldwide by scientists is the International System of Units—abbreviated SI from its French name, "Système International."[2,5,7] SI is based upon the decimal and metric systems, thus simplifying the conversion of one unit to another.[3]

Only three countries in the world, at least according to current folklore,—the United States, Burma (also known as Myanmar), and Liberia—have not officially adopted, or are not fully committed to, the metric system.[6] Therefore, with apologies to Burma and Liberia, we can justify calling the nonmetric system the "American" system. However, American scientists, including exercise physiologists, have adopted SI metric units of measure. Although U.S. legislation has discouraged the use of the nonmetric system, the practice is dying slowly. Americans often overlook metric designations on such objects as engine sizes (e.g., cubic centimeters), food containers (e.g., grams), and liquid containers (e.g., liters). Metric markers in America are sometimes found on road mileage/kilometer signs, auto tachometers, and speed-limit signs. Some U.S. buildings display temperature readings in Celsius. As more students become familiar with SI nomenclature—specifically, the metric system—perhaps the U.S. population will adopt, and use routinely, the worldwide metric system.

## Recognizing and Reporting SI (Metric) Units

Students need to recognize SI units of measure when they see them and know how to report them after making measurements. As when learning any language, students must be concerned with the spelling, punctuation, and grammar of the SI "language." With respect to spelling, the SI guide published by the U.S. National Institute of Standards and Technology permits American scientists to spell *liter* and *meter* as such, whereas a Briton may spell them as litre and metre, respectively.[5] As noted in Chapter 1, although William Kelvin originated the kelvin temperature scale, the name is not capitalized when referring to the unit because the kelvin is adopted as one of the *base units* of the International System of units.[5] The same rationale applies when spelling out some of the derived units whose names are those of persons, such as newton, watt, joule, and pascal. When expressing the full name, not the abbreviation, of a two-component unit such as newton meter, use a space between the two words. Do not use a hyphen (e.g., not "newton-meter") and do not link terms into a single word (e.g., not "newtonmeter").

Obviously, symbols and abbreviations of measuring units avoid spelling problems and are convenient and space efficient. However, abbreviations (e.g., kg) and symbols (e.g., °) of measuring units should be used only when associated with the numeric value.[7] For example, *kilogram* should not be abbreviated as expressed in this sentence, but the abbreviation should be used if reporting that a person's body weight (mass) is 60 kg. Abbreviations are not capitalized unless associated with a person's name, such as N, W, C, and K, for Misters Newton, Watt, Celsius, and Kelvin, respectively.

Plural abbreviations are not acceptable in the SI. Thus, 60 kg or 175 cm is not reported as 60 kgs or 175 cms. Abbreviations are followed by a period only for the American abbreviation for inches (in.) or at the end of a sentence. A space is also required between the numeral and the unit; thus, the technician records "60 kg," not "60 kg," or records "10 %," not "10%." One exception to the rule regarding a space is when using the symbol for degrees as in "an angle of ninety degrees (90°)." When abbreviating a two-component unit, use a centered dot (·) to separate each component. Thus, you would abbreviate "newton meter" as "N·m." Unit abbreviations and unit names are not mixed; thus, do not use a mixed expression, such as "newton·m" or "N·meter." Similarly, do not mix numerals and names; thus, "the static force was 500 N," not ". . . 500 newtons," or ". . . five-hundred N."

The recommended style of expressing *per* in combined units, such as liters per minute, is to use the centered dot preceding the unit with its negative exponent. Thus, the unit would appear as $L \cdot min^{-1}$, unless this is impractical for certain computers or typewriters. In that case, one slash (solidus; /) is acceptable (e.g., L/min). However, it is incorrect to use more than one solidus (accent on the first syllable *säl*) per expression, such as "ml/kg/min." The latter could be expressed with one solidus as ml/(kg·min) or as $ml \cdot kg^{-1} \cdot min^{-1}$.

The SI style also calls for scientists to record some numbers differently from what we are used to seeing. The general rule for numerical values with more than four digits is to insert a blank space to separate groups of three digits on either side of the decimal. For example, we are familiar with writing the number 10,500 with a comma, but we need to write it as 10 500 in accordance with SI recommendations (requirements). The one exception to this is when there are only four digits to the left or right of the decimal. For example, it is appropriate to record the number as 1500, or 1 500 for uniformity of numbers in a table, but not as 1,500. One reason for such rules is to avoid confusion where some countries use a comma instead of a decimal point.

## Variables and Units of Measure

Numerous variables were introduced and defined in Chapter 1. A main purpose of this chapter is to describe the units in which these quantities are typically measured and expressed. Emphasis is placed on SI (metric) units, but American or customary units are also discussed because of their frequent usage, at least in the United States.

### Mass

Mass (M) is considered an SI base quantity and is represented by the SI base unit, the kilogram (kg). One of the most common measurements of mass in exercise physiology is body mass. Although the term *body mass* is the more appropriate term, *body weight* is still overwhelmingly used in the United States. For this reason, whenever the variable mass refers to the mass of the human body, the term body weight will typically be used throughout this laboratory manual. Otherwise, the term mass will be used to refer to the mass of any other object. In some cases, where body weight is being described, it may be expressed in pounds (lb), again due to the popularity of the unit in the United States. But whenever body weight is described in pounds (mostly in tables or figures), it will also be expressed in kilograms.

### Length and Distance

Length is also an SI base quantity described in the SI base unit, the meter (m). Longer lengths and distances are described in kilometers (km). For shorter lengths, a meter can be subdivided into 10 decimeters (dm), 100 centimeters (cm), or 1000 millimeters (mm). Table 2.1 lists common metric prefixes and the decimal and exponent they represent. The term height describes the "vertical length" of a person, which is expressed in meters or centimeters. It is actually more appropriate to refer not to a person's height, but to his or her *stature*. But again, because of the common usage of the term height, it will be used throughout the laboratory manual more so than the term stature.

### Force

The recommended measuring unit for force is newton (N), named after mid-19th-century scientist Isaac Newton. The newton is a special name given to a derived SI unit, being mathematically derived from the three base quantities mass (kg), length (m), and time (s). Technically, the most appropriate unit in which to express force is $kg \cdot m \cdot s^{-2}$, due to its being the product of mass and acceleration. But the special term newton is more commonly used, to acknowledge the contributions made by this important scientist. Although the kilogram (kg) is a unit of mass, laboratories often use it as a measure of the force exerted to lift a weight, crank a cycle ergometer, or push against a dynamometer. Many grip strength dynamometers display force in both pounds and kilograms.

**Table 2.1 Decimal and Exponent Expressions of SI (Metric) Prefixes**

| Decimal | Exponent | Prefix | Length (meter) | Mass (gram) | Volume (liter) |
|---|---|---|---|---|---|
| 1 000 000 | $10^{6}$ | mega | - | megagram (Mg) | - |
| 1 000 | $10^{3}$ | kilo | kilometer (km) | kilogram (kg) | kiloliter (kl) |
| 100 | $10^{2}$ | hecto | hectometer (hm) | hectogram (hg) | hectoliter (hl) |
| 10 | $10^{1}$ | deka | dekameter (dam) | dekagram (dag) | dekaliter (dal) |
| 1 | $10^{0}$ | - | meter (m) | gram (g) | liter (L) |
| 0.1 | $10^{-1}$ | deci | decimeter (dm) | decigram (dm) | deciliter (dl) |
| 0.01 | $10^{-2}$ | centi | centimeter (cm) | centigram (cm) | centiliter (cl) |
| 0.001 | $10^{-3}$ | milli | millimeter (mm) | milligram (mg) | milliliter (ml) |
| 0.000 001 | $10^{-6}$ | micro | micrometer (μm) | microgram (μg) | microliter (μl) |

### Work

The preferred unit for expressing work (w) is the joule (J) because it represents the "totality" of work rather than separating it into its two components—force and distance. Larger quantities of work can be expressed in kilojoules (kJ). When work is calculated as the product of the force unit (newton) and the distance unit (meter), another acceptable derived unit is produced—the newton meter (N·m). In the same way that force is still sometimes described in kg, work can still be described in kilogram meters (kg·m).

### Power

The recommended unit for power (P) is the watt (W), a special name given in honor of Scottish inventor James Watt. Like the joule, the watt describes power in its totality. When power is broken down into its components, it is the product of the force (N) times the distance (m) that an object moves divided by the time (s) spent moving the object—or the derived unit, $N \cdot m \cdot s^{-1}$. Thus, 1 watt can be defined as either 1 $N \cdot m \cdot s^{-1}$ or as 1 $J \cdot s^{-1}$ since 1 N·m (derived unit) is equal to 1 J (special name for the derived unit). Although it is not an acceptable SI unit of power, you will still sometimes see power described in $kg \cdot m \cdot min^{-1}$, especially with reference to cycle ergometry.

### Energy

The terms energy (E) and work are highly related to one another, in fact so much so that they use the same unit—the joule (J). The joule is named for James Joule, who proposed the law of the conservation of energy. The joule is the universally approved unit of measure for metabolic energy release, which is the result of energy done (work) and energy wasted (heat).[4] Energy is commonly expressed in kilocalories (kcal) in the United States, but this is not an SI unit of energy.

**Energy expenditure** at rest and during exercise can be estimated through indirect calorimetry using the measurement of oxygen uptake. It can be assumed that for every 1 liter of oxygen uptake, approximately 5 kcal or 21 kJ of energy is expended. These values are only approximations and are influenced slightly by exercise intensity with more energy expended per liter at higher intensity. (Data for more specific energy equivalents for 1 liter of oxygen, ranging from 4.69 to 5.05 $kcal \cdot L^{-1}$, can be found in Table 15.8.) Once the oxygen uptake and hence the oxygen cost is known, it is possible to estimate the *caloric expenditure* or *kilojoule expenditure* simply by multiplying the liters of oxygen consumed by 5 (Eq. 2.1a) or by 21 (Eq.2.1b), respectively.

$$\text{Energy (caloric) expenditure (kcal)} = \text{Oxygen uptake } (L \cdot min^{-1}) * 5 \quad \text{Eq. 2.1a}$$

$$\text{Energy (Kilojoule) expenditure (kJ)} = \text{Oxygen uptake } (L \cdot min^{-1}) * 21 \quad \text{Eq. 2.1b}$$

### Speed and Velocity

Speed and velocity (v) are derived quantities based on distance and displacement, respectively, divided by time. The most appropriate unit in which to express speed and velocity is $m \cdot s^{-1}$, derived from the two base units meters and seconds. However, numerous other acceptable SI units can be derived from any unit of length (m, km, etc.) and time (s, min, h, etc.)—for example, $m \cdot min^{-1}$ and $km \cdot h^{-1}$. Speed limits in the United States are still posted in miles per hour ($mi \cdot h^{-1}$), although an attempt is being made to phase out this unit in favor of the SI unit of kilometers per hour ($km \cdot h^{-1}$).

### Angular Velocity

Angular velocity (ω), instead of being linear, describes the velocity at which an object rotates. The preferred SI unit for expressing angular velocity is radians per second ($rad \cdot s^{-1}$). However, another unit that is frequently used, especially with regard to isokinetic dynamometry, is degrees per second ($deg \cdot s^{-1}$ or $° \cdot s^{-1}$). Because there are 2π radians in a complete circle, one radian is about 57.3 °, and therefore 1 $rad \cdot s^{-1}$ is equivalent to 57.3 $° \cdot s^{-1}$(or $deg \cdot s^{-1}$).

### Torque

Torque (τ) is a derived quantity based on the "**moment of force**" created. The moment of force is the mathematical product of the length of the moment arm (measured from the center of rotation to the point where the force is applied) and the force applied at that moment arm length. The SI unit for torque is the newton meter (N·m), derived from the two base units of force (N) and length (m). In many earlier published studies involving isokinetic dynamometry, peak torque was described in foot pounds (ft·lb), but in general this unit is no longer used in scientific publications.

### Volume

The SI unit of measure for volume (V) is the liter (L). Although logically *liter* would be abbreviated by a lowercase *l*, an uppercase *L* is acceptable and, in fact, is often used instead so that it is not confused with the numeral 1. Numerous volumes will be discussed in this laboratory manual related to lung volumes, pulmonary ventilation, cardiac output, and stroke volume, and the uppercase *L* will be used. For smaller volumes, a liter can be subdivided into 10 deciliters (dl), 100 centiliters (cl), or 1000 milliliters (ml); in these two-letter abbreviations, the lowercase *l* will be used.

## Meteorological Units

The primary meteorological concerns of the exercise physiologist are temperature, relative humidity, and barometric pressure. The units presented here for these terms are those accepted by the scientific community or adopted as the SI style.

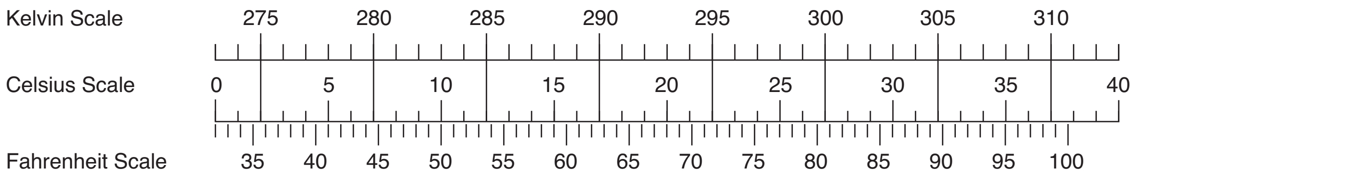


**Figure 2.1 Conversion of temperature between different scales.**

## Temperature

The base unit of thermodynamic temperature (*T*) is the kelvin (K), named in honor of William Thomson Baron Kelvin. The Kelvin scale for describing temperature is based on an absolute zero (0 K), the lowest temperature possible in any macroscopic system. This absolute zero is equal to −273.15 °C (≈ −273 °C). For the purpose of this laboratory manual, converting temperature between kelvin units (K) and Celsius degrees (°C) will be done by adding or subtracting 273, as seen in Equation 2.2a and 2.2b. Although the kelvin is the base unit of temperature, most laboratory thermometers display in Celsius degrees, which are accepted SI units. Therefore, for selected calculations involving volume conversions, students need to be able to convert temperatures from Celsius degrees to kelvin units.

°C to K: K = (°C + 273) Eq. 2.2a

K to °C: °C = (K − 273) Eq. 2.2b

The Fahrenheit temperature scale and Fahrenheit degrees are not accepted by the International System, but they are described here because they are still so prevalent in the United States. The primary purpose of being able to convert °F to °C would be if the only thermometer or temperature available was in °F. For this conversion, it is necessary not only to change the "zero point" of the scale, designated by the freezing point of water (0 °C or 32 °F) but also to change the size of the degrees. Because there are 9 F degrees for every 5 C degrees, we multiply or divide by 9/5 (1.8). Converting temperatures between the Fahrenheit and Celsius scales is done using the formulas shown in Equation 2.3a and 2.3b. Figure 2.1 shows the conversion of temperatures between the three temperature scales.

°F to °C: °C = (°F − 32) / 1.8 Eq. 2.3a

°C to °F: °F = (°C ∗ 1.8) + 32 Eq. 2.3b

## Relative Humidity

Relative humidity (RH) indicates the relative amount of water in the air. It is measured in the laboratory with an instrument called a hygrometer, which displays relative humidity in units of percent (e.g., 50 %). If the RH is 100 %, the air contains the most amount of water it can possibly hold at that air temperature. Air can hold more water at higher temperatures than it can at lower temperatures. Ideally, laboratories should also have instruments that display directly or indirectly the wet-bulb globe temperature index (WBGT index). This index considers the interaction of relative humidity with air temperature and radiant temperature and is important in identifying risk of heat illness.

## Barometric Pressure

The pressure being exerted by the "weight" of the atmosphere is measured with an instrument called a barometer, so it is commonly referred to as *barometric pressure* ($P_B$). The derived unit for pressure is $N \cdot m^2$ based on it being force (N) exerted per unit area ($m^2$), which is specially named the pascal (Pa), in honor of 17th-century scientist Blaise Pascal. Because the unit is small, barometric pressure is commonly described in hectopascals (1 hPa = 100 Pa) or kilopascals (1 kPa = 1000 Pa). The standard barometric pressure at sea level is 1013 hPa. This same pressure (1013 hPa) can also be described as 1013 millibar (mbar) because the hPa and the mbar have the same numerical value. The millibar is a common unit used by meteorologists.

Barometric pressure, especially in the United States, is commonly described in other units not accepted as SI units. It is described in millimeters of mercury (mm Hg), or torr, and in inches of mercury (in. Hg). Standard barometric pressure, reported earlier as 1013 hPa, is also equivalent to 760 mm Hg (or torr) and 29.92 in. Hg. For much the same reason as was discussed with regard to temperature, it is useful to be able to convert between different units of pressure (Eq. 2.4a through 2.4d) if the only available measuring device does not measure in pascals or hPa.

mm Hg to hPa: hPa = mm Hg ∗ 1.333 Eq. 2.4a

hPa to mm Hg: mm Hg = hPa ∗ 0.75 Eq. 2.4b

in. Hg to hPa: hPa = in. Hg ∗ 33.864 Eq. 2.4c

hPa to in. Hg: in. Hg = hPa ∗ 0.0295 Eq. 2.4d

The American College of Sports Medicine (ACSM) permits exceptions to the SI units for physiological and gas pressures.[1] Thus, blood pressure units and lung pressures are reported in millimeters of mercury (mm Hg) in the journal *Medicine and Science in Sports and Exercise*.

**Table 2.2 Conversions of SI (Metric) Units and American (Customary) Units**

| **Mass and Weight (gram; g)** | **Speed and Velocity** (meter·second$^{-1}$; m·s$^{-1}$) |
|---|---|
| 1 g = 1000 mg = 0.0022 lb = 0.0352 oz | 1 m·s$^{-1}$ = 2.2371 mi·h$^{-1}$ (mph) = 3.281 ft·s$^{-1}$ |
| 1 oz = 28.3495 g | 1 m·min$^{-1}$ = 0.0373 mph = 3.281 ft·min$^{-1}$ |
| 1 lb = 16 oz = 453.59 g = 0.4536 kg | 1 km·hr$^{-1}$ = 1000 m·h$^{-1}$ = 0.6215 mph |
| 1 kg = 1000 g = 2.2046 lb = 35.2736 oz | 1 mph = 1.6093 km·h$^{-1}$ = 26.822 m·min$^{-1}$ = 0.447 m·s$^{-1}$ |
| accel of gravity (g) = 9.81 m·s$^{-2}$ = 32.2 ft·s$^{-2}$ | = 1.4667 ft·s$^{-1}$ |
| | |
| **Length and Height (meter; m)** | **Angular Velocity** (radian·second$^{-1}$; rad·s$^{-1}$) |
| 1 m = 1000 mm = 1.0936 yd = 3.281 ft = 39.37 in. | 2 $\pi$ rad (~ 6.2832 rad) = 360° *(1 full circle)* |
| 1 yd = 3 ft = 0.914 m = 91.4 cm | 1 rad = 360° / 2$\pi$ = 57.2958° |
| 1 ft = 12 in. = 0.3048 m = 30.48 cm | 1 rad·s$^{-1}$ = 57.2958°·s$^{-1}$ |
| 1 in. = 25.4 mm = 2.54 cm = 0.0254 m | 1°·s$^{-1}$ = 0.0175 rad·s$^{-1}$ |
| 1 km = 1000 m = 0.6214 mile = 1093.6 yd | |
| 1 mile = 1.609 km = 1609.35 m | **Torque (newton meter; N·m)** |
| | 1 N·m = 0.1020 kg·m = 0.7375 ft·lb |
| **Force (newton; N)** | 1 kg·m = 9.8067 N·m = 7.2307 ft·lb |
| 1 N = 0.1020 kg = 0.2248 lb | 1 ft·lb = 1.3559 N·m = 0.1393 kg·m |
| 1 kg = 1000 g = 2.2046 lb = 9.8067 N | |
| 1 lb = 0.4536 kg = 453.59 g | **Volume (liter; L)** |
| | 1 L = 1000 ml = 1.0567 qt = 33.81 fluid ounce (fl oz) |
| **Work (joule; J)** | 1 qt = 32 fl oz = 0.9464 L = 946.4 ml |
| 1 J = 1 N·m = 0.1020 kg·m = 0.7375 ft·lb | 1 ml = 0.0338 fl oz |
| 1 kg·m = 9.8067 J = 9.8067 N·m = 7.2307 ft·lb | 1 fl oz = 0.0313 qt = 0.0296 L = 29.574 ml |
| 1 ft·lb = 1.3559 J = 1.3559 N·m = 0.1393 kg·m | |
| | **Pressure (pascal; Pa)** |
| **Power (watt; W)** | 1 pascal (Pa) = 1 N·m$^{-2}$ = 0.000145 lb·in.$^{-2}$ |
| 1 W = 1 J·s$^{-1}$ = 1 N·m·s$^{-1}$ | 1 hectopascal (hPa) = 100 Pa = 0.1 kilopascal (kPa) |
| 1 W = 60 J·min$^{-1}$ = 60 N·m·min$^{-1}$ = 6.1183 kg·m·min$^{-1}$ | 1 hPa = 1 millibar (mbar) = 0.75 torr = 0.75 mm Hg |
| 1 N·m·min$^{-1}$ = 0.0167 W = 0.1020 kg·m·min$^{-1}$ | 1 torr = 1 mm Hg = 1.333 hPa = 1.333 mbar |
| 1 kg·m·min$^{-1}$ = 0.1634 W = 9.8067 N·m·min$^{-1}$ | 1 atmosphere (atm) = 1013 hPa = 1013 mbar |
| 1 kW = 1000 W = 1.34 horsepower (hp) | = 760 torr = 760 mm Hg = 29.92 in. Hg = 14.7 lb·in.$^{-2}$ |
| | |
| **Energy (kilojoule; kJ)** | **Temperature (kelvin; K)** |
| 1 kJ = 1000 J = 0.239 kcal | °C to K: K = (°C + 273) |
| 1 kcal = 4.186 kJ = 4186 J | K to °C: °C = (K − 273) |
| 1 kcal = 426.85 kg·m *(at 100 % efficiency)* | °F to °C: °C = (°F − 32) / 1.8 |
| 1 L $VO_2$ ≈ 21 kJ ≈ 5 kcal *(at R = 0.96)* | °C to °F: °F = (°C * 1.8) + 32 |

## Metric Conversions

Metric units are simpler to use than the traditional or customary units of the American system. The metric system facilitates the conversion of base quantities (e.g., mass, length, time) expressed in base units (e.g., kilogram, meter, second) into derived quantities (e.g., force, power, speed, volume) expressed in derived units (e.g., m·kg·s$^2$, m$^2$·kg·s$^{-3}$, m·s$^{-1}$, m$^3$), respectively. The systematic nature of metric units is somewhat diminished, however, by the use of special names and symbols, such as expressing force in newtons (N) instead of m·kg·s$^{-2}$, or expressing pressure in pascals (Pa) instead of m$^{-1}$·kg·s$^{-2}$.

The metric system is also easier when it comes to measuring small or large quantities. For example, one meter (1m) can be systematically divided by 10 to create 10 decimeters (10 dm), or by 100 to create 100 centimeters (100 cm), or by 1000 to create 1000 millimeters (1000 mm). If long lengths or distances are being measured, 1 meter can be multiplied by 1000 (1000 m) to create one kilometer (1 km). This type of systematic approach does not apply to customary American units. The yard is the nonmetric equivalent of the meter. When a yard is divided into smaller units, it is divided into 3 feet and further into 36 inches. For measuring long distances, it is multiplied by 1760 (1760 yd) to create 1 mile (1 mi).

Table 2.2 provides a summary of conversion factors for converting between SI (metric) units and American (customary) units. It will be helpful to refer to this table frequently while reading the following discussion of metric conversions. These same conversion factors are also included in Appendix D for easy reference from any point throughout the manual.

### Mass (Weight) Measures

Every exercise physiology student is expected to respond quickly and correctly in SI units to the question, "What is your body weight?" When expressing body weight (or mass), the correct response is to describe it in kilograms (kg). Components of body composition, including fat weight and lean weight (or lean body mass), are also expressed in kilograms. It is also appropriate to describe body weight in grams, but the more common measure is kilograms. If body weight is recorded on a measuring instrument that displays only pounds, it can be converted to kilograms by multiplying or dividing by the appropriate conversion factors (Eq. 2.5a and 2.5b). For smaller masses, the gram can be subdivided into 10 decigrams (dg), 100 centigrams (cg), and 1000 milligrams (mg).

Weight, X kg = **151 lb** ∗ (0.4536 kg / 1 lb)
= **68.5 kg** Eq. 2.5a

Weight, X kg = **151 lb** ∗ (1 kg / 2.2046 lb)
= **68.5 kg** Eq. 2.5b

Instead of body weight being considered a mass, it can be thought of as a force, as in the force being exerted downward on a scale. When this is the case, body weight is expressed in newtons (N) and can be calculated by one of two conversion factors (Eq. 2.6a and 2.6b). A specific example of this can be found in Chapter 8, where body weight (or mass) in newtons (N) is used in conjunction with vertical distance to measure leg power.

Weight, X N = **151 lb** ∗ (4.448N / 1 lb) = **672 N** Eq. 2.6a

Weight, X N = **151 lb** ∗ (1N / 0.2248 lb) = **672 N** Eq. 2.6b

## Length (Height) Measures

The next question would be, "What is your height?" Most devices for measuring height found in an exercise physiology laboratory should allow for the measurement of height directly in SI units. So measuring and expressing height (in centimeters) should be simple. When the measuring device displays inches instead of centimeters, however, it is necessary to convert them by multiplying or dividing the height in inches by one of two conversion factors (Eq. 2.7a and 2.7b). These two conversion factors are related mathematically in that they are reciprocals of one another.

Height, X cm = **70.5 in.** ∗ (2.54 cm / 1 in.)
= **179 cm** Eq. 2.7a

Height, X cm = **70.5 in.** ∗ (1 cm / 0.3937 in.)
= **179 cm** Eq. 2.7b

## Measurement Error and Significant Figures

No mention has been made to this point about **measurement error.** It is virtually impossible to measure any variable described in this laboratory manual (e.g., mass, length, force, power) without some degree of error. The error of any laboratory measurement is what determines the **precision** and **accuracy** with which that measurement can be made. The term *precision* refers to the *reliability* or reproducibility of a measurement or instrument. Precision is frequently characterized in terms of the variability of the measurement. A precise measure or instrument yields a low variability (standard deviation or standard error) and a high degree of reliability (high test-retest correlation coefficient). The term *accuracy* refers to the *validity* of the measurement, or how close a measurement is to the correct or "real" value (if it is known). The goal of every scientist and exercise physiology student should be to develop and use laboratory instruments and tests that are both precise and accurate.

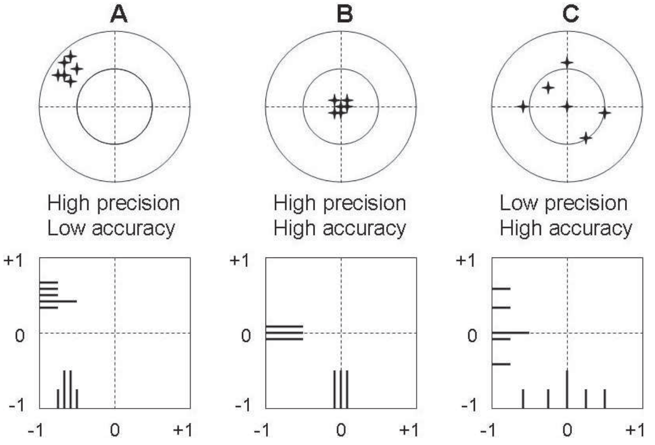


**Figure 2.2 Demonstration of precision and accuracy. The upper portion of the figure shows six shots taken at each of three targets. The lower portion is the frequency with which each shot hit the target, with 0 in both directions (X and Y) being a "perfect" shot.**

A frequently used analogy to help demonstrate precision and accuracy is shooting at a target. Figure 2.2 shows three targets (A, B, and C) at which six shots each have been fired. Target B shows both high precision (the shots are tightly grouped with little variability or error) and high accuracy (the shots hit the correct or "real" target). Target A shows the same high precision (tightly grouped shots), but the accuracy is low because the shots do not hit the center of the target. Target C, even though it shows low precision (the shots are widespread with more variability or error), shows high accuracy because "on average" the shots are evenly arranged around the correct target. In the exercise physiology laboratory, a measuring device that is precise and accurate follows this same analogy, providing measurements that are tightly clustered around the "real" value.

It is important to be able to express the precision of a measurement or measuring device. Let's use a skinfold caliper as an example. Assume that a measuring device (e.g., ruler, scale, skinfold caliper) can be used to measure or "estimate" a quantity to one decimal place farther than the last decimal place on the scale of the device. So for the skinfold caliper, assuming it is marked in millimeters, a tester could measure a skinfold thickness to the closest millimeter (e.g., between 25 and 26 mm) and could still "estimate" the value between those two marks (e.g., 25.5 mm). So the *precision* of the skinfold caliper is considered 0.1 mm, and each of the figures in the estimated value (25.5 mm) is considered a **significant figure** (or significant digit). It would not be appropriate to express this value as 25.5000, because this is beyond the precision of the device.

Counting significant figures follows a general rule. Begin at the left end of the number and (ignoring any decimal point) count the number of digits until the precision of the measurement is reached. In the example above (25.5 mm), the skinfold thickness has three significant figures. Counting significant figures becomes difficult when the precision of the measuring device is uncertain. Assume in this chapter (for the purpose of unit conversions) that any values given are within the precision of the measuring device. An effort is made in each subsequent chapter to describe the precision and accuracy with which each measurement is made, so that the number of significant figures can be correctly determined.

## Other Metric Measures and Conversions

The metric system facilitates the conversion from mass, length, and time measures to a variety of derived quantities, including force, work, power, energy, speed, torque, volume, pressure, and more. The emphasis in this laboratory manual is on the conversion of American or cus-tomary units (e.g., lb, ft·lb, mph, fl oz, lb·in.$^2$) into SI or metric units. This is most often necessary because a specific measuring device being used (especially an older one) does not display in metric units. Some examples of quantities being converted from American or customary units into metric units are shown in Equations 2.8a through 2.8h. Notice that each answer (or converted unit) is expressed in the *same number of significant figures* as the original quantity. This practice helps maintain the same level of precision before and after the conversion between units.

Force, X N = **71.5 kg** ∗ (9. N / 1 kg)
= **701 N** Eq. 2.8a

Work, X J = **101 ft·lb** ∗ (1.3559 J / ft·lb)
= **137 J** Eq. 2.8b

Power, X W = **515 kg·m·min$^{-1}$**
∗ (1 W / 6.12 kg·m·min$^{-1}$) = **84.2 W** Eq. 2.8c

Energy, X kJ = **125 kcal** * (4.186kJ / 1kcal)
= **523 kJ** Eq. 2.8d

Speed, X m·s$^{-1}$ = **35 mph**
∗ (1 m·s$^{-1}$ / 2.2371 mph) = **16 m·s$^{-1}$** Eq. 2.8e

Torque, X N·m = **63 ft·lb** * (1.3559 N·m / ft·lb)
= **85 N·m** Eq. 2.8f

Volume, X ml = **30.5 fl oz**
∗ (29.574 ml / 1 fl oz) = **902 ml** Eq. 2.8g

Pressure, hPa = **18.55 lb·in$^2$**
∗ (1 hPa / 0.0145 lb·in$^2$) = **1279 hPa** Eq. 2.8h

## The Concept of Unit Analysis

In reviewing Equations 2.8a through 2.8h, notice that some quantities are multiplied by the metric conversion factor, and others are divided. It is easy to get careless and multiply or divide by the incorrect factor and end up with the wrong answer. **Unit analysis** can increase the likelihood of getting the correct answer. It is a concept where special attention is given to the units, such that the problem is set up to yield the desired units before the calculation is performed.

As an example, look again at the conversion made in Equation 2.8g, where 30.5 fl oz is converted to 902 ml. Before performing the calculation, the problem is set up to insure that the correct units (ml) will result, as shown in Equation 2.9a. Once it is confirmed that the units are correct, the appropriate conversion factor can be chosen, in this case 29.574 ml = 1 fl oz. Furthermore, it should be clear that multiplying by the conversion factor will yield the correct units and therefore the correct answer. The problem could also be worked using the reciprocal correction factor, 1 ml = 0.0338 fl oz. In this case, based on an analysis of the units, the conversion factor should go in the denominator, again yielding the correct answer (Eq. 2.9b).

$$\text{X ml} = 30.5\ \cancel{\text{fl oz}} \ast \frac{29.574\,\text{ml}}{1\ \cancel{\text{fl oz}}} = 902\,\text{ml} \qquad \text{Eq. 2.9a}$$

$$\text{X ml} = 30.5\ \cancel{\text{fl oz}} \ast \frac{1\,\text{ml}}{0.0338\ \cancel{\text{fl oz}}} = 902\,\text{ml} \qquad \text{Eq. 2.9b}$$

Another example of unit analysis is to convert speed from miles per hour into meters per second. The conversion could be done in one step using one conversion factor (Eq. 2.10a). Instead, assume the conversion factor is not known, but what is known is that there are 1609.35 meters in 1 mile, 60 minutes in 1 hour, and 60 seconds in 1 minute. By setting up the problem with the units in the correct position (either in the numerator or denominator), so that the resultant units are meters per second, the calculation yields the same results, 55 mph equals 25 m·s$^{-1}$ (Eq. 2.10b).

$$\text{X m·s}^{-1} = \mathbf{55}\ \cancel{\text{mph}} \ast \frac{0.447\ \text{m·s}^{-1}}{1\ \cancel{\text{mph}}} = \mathbf{25}\,\text{m·s}^{-1} \qquad \text{Eq. 2.10a}$$

$$\text{X m·s}^{-1} = \frac{\mathbf{55}\ \cancel{\textbf{mi}}}{\cancel{\text{h}}} \ast \frac{1609.35\,\text{m}}{1\ \cancel{\text{mi}}} \ast \frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}} \ast \frac{1\ \cancel{\text{min}}}{60\ \text{s}} = \mathbf{25}\ \text{m·s}^{-1} \qquad \text{Eq. 2.10a}$$

## Summary

The Système International (SI), or metric system, is the unit system of choice in the scientific community and is used by most people throughout the world. For this reason, the exercise physiology student must use and understand this system. The SI base quantities (e.g., length, mass, time, etc.) and SI base units (e.g., meter, kilogram, second, etc.) are used to derive all other quantities and units. Several derived units, such as newton, watt, and joule, have been named in honor of the scientists who have made significant contributions to various fields of science. Until the United States fully adopts

## BOX 2.1 Chapter Preview/Review

**What does the term *SI* mean?**
**When are abbreviations of units capitalized?**
**Who are some of the scientists who have had a metric unit named in their honor?**
**What is the relationship between meters, kilometers, and millimeters?**
**Which variables incorporate force?**
**What is the caloric equivalent of 1 L of oxygen uptake?**
**In what three scales may temperature be expressed?**
**In what units may pressure be expressed?**
**What do the terms *precision* and *accuracy* mean?**
**What is meant by the concept of unit analysis?**

the SI system, wherever or whenever nonmetric units are used, students must understand how they can be converted. Remember also that nearly all measurements made in the exercise physiology lab are made with some degree of error. Therefore, the precision and accuracy of all measurement devices should be considered when possible, with the resultant measurements expressed in significant figures when the precision of the device is known.

At the conclusion of each chapter there are two forms: a **Homework** form and a **Lab Results** form. Form 2.1 (Homework) is a set of problems that the student may complete either as *preview* for an upcoming lab or as *review* of a completed lab, in whichever manner the instructor decides to use it. Form 2.2 (Lab Results) provides an opportunity for the student to collect laboratory data, and in this particular case to study the variables, instruments, and units discussed in Chapter 2. The data recorded on the Lab Results form in any chapter may also be used by the student to write a lab report or be used in any other project assigned by the instructor.

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# Form 2.1
HOMEWORK

NAME ______________________ DATE ________ SCORE ________

## Units of Measure

| | | | | | | |
|---|---|---|---|---|---|---|
| Mass / Weight | X lb = | **78.5** | kg * | ______________ | = ______ | lb |
| Length / Height | X mile = | **5.2** | km * | ______________ | = ______ | mi |
| Force | X lb = | **401** | N * | ______________ | = ______ | lb |
| Work | X N·m = | **355** | ft·lb * | ______________ | = ______ | N·m |
| Power | X kg·m·min$^{-1}$ = | **305** | W * | ______________ | = ______ | kg·m·min$^{-1}$ |
| Energy | X kcal = | **1013** | J * | ______________ | = ______ | kcal |
| Speed / Velocity | X mph = | **122** | km·h$^{-1}$ * | ______________ | = ______ | mph |
| Angular Velocity | X deg·s$^{-1}$ = | **1.5** | rad·s$^{-1}$ * | ______________ | = ______ | deg·s$^{-1}$ |
| Torque | X ft·lb = | **45** | N·m * | ______________ | = ______ | ft·lb |
| Volume | X ml = | **2.75** | cup * | ______________ | = ______ | ml |
| Pressure | X torr = | **999** | mbar * | ______________ | = ______ | torr |
| Temperature | X K = | **212** | °F = | ______________ | = ______ | K |

# Form 2.2

LAB RESULTS

NAME ________________________ DATE ________ SCORE ________

## Units of Measure

To gain an appreciation for variables and units of measure, take a tour of your exercise physiology lab and complete the following laboratory exercise *within the time available*.

Observe various laboratory instruments (e.g., scale, stadiometer, etc.). Attempt to identify an instrument in the lab that measures each of the variables listed below (e.g., weight, height, etc.) within the time available. Record the units in which the instrument measures (e.g., kg, cm, etc.). Record the range within which the instrument measures and the precision (or accuracy) with which it measures. *Some examples are provided.*

Take one measurement with the instrument in the units indicated (or alternatively observe the measurement scale on the instrument and record any value). Convert the measured or observed units into the units indicated below using the conversion factors in Appendix D. *Some examples are provided.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Weight | Weight = | **85.1** | kg * | 2.2046 lb / 1 kg | = | **188** | lb | |
| Scale | Units | kg, lb, N | Range | 0–200 kg | Precision | 0.1 kg | | |
| Height | Height = | **175.0** | cm * | 0.3937 in. / 1 cm | = | **68.9** | in. | |
| Stadiometer | Units | cm, in. m | Range | 0–200 cm | Precision | 0.1 cm | | |
| Force | Force = | ______ | kg * | ______________ | = | ______ | N | |
| Grip dynamometer | Units | ______ | Range | ______ | Precision | ______ | | |
| Power | Power = | ______ | W * | ______________ | = | ______ | $kg \cdot m \cdot min^{-1}$ | |
| Cycle ergometer | Units | ______ | Range | ______ | Precision | ______ | | |
| Speed | Speed = | ______ | mph * | ______________ | = | ______ | $km \cdot h^{-1}$ | |
| Treadmill | Units | ______ | Range | ______ | Precision | ______ | | |
| Volume | Volume = | ______ | L * | ______________ | = | ______ | ml | |
| Spirometer | Units | ______ | Range | ______ | Precision | ______ | | |
| Pressure | Pressure = | ______ | mm Hg * | ______________ | = | ______ | torr | |
| Sphygmomanometer | Units | mm Hg, torr | Range | 0–300 mm Hg | Precision | 1 mm Hg | | |
| Temperature | Temperature = | ______ | °F = | ______________ | = | ______ | K | |
| Thermometer | Units | ______ | Range | ______ | Precision | ______ | | |

CHAPTER 3

# Collection of Basic Data

Nearly all test forms (data collection forms) include basic information or **basic data** about the participants and the conditions under which the data are collected. The information about the participants is typically referred to as either basic data or vital data, including such characteristics as name, gender/sex, age, height and weight. Sometimes more detailed vital data (e.g., heart rate, blood pressure, body temperature) are recorded. It is also common to record the conditions under which the data are collected, including test date, time of day, and in some cases the environmental conditions (e.g., temperature, barometric pressure, relative humidity). Form 3.2, at the end of this chapter, may be used to record basic data and assist in the evaluation of certain characteristics (especially height and weight) based on a review of comparative data.

## Recording Basic Data

The art and technical skills of administering tests include the precise and thorough recording of all basic data. Some of the comments here may appear obvious, but there are numerous occasions when seemingly obvious items of basic data are omitted, much to the later chagrin of the investigators or the participants.

### Name, Date, and Time

**Name** is typically written with the last name first, followed by a comma and then the first name. In potentially publishable research, an identification number (ID#) replaces the name for anonymity or confidentiality. Also, to resolve discrepancies or errors, especially if technicians have interobserver differences, it helps to include the technician's initials.

The test **date** is presented with the month in numerical form at the beginning; for example, September 4, 2006 would be recorded as 9/4/06 (or 09/04/06). Besides recording these on the data collection form (e.g., Form 3.2), name and date should be recorded on any type of chart paper, such as that from the electrocardiogram or isokinetic dynamometer.

It is important to record test **time** in addition to date on the data collection form because of the possible daily or monthly variations of many biological and performance variables (e.g., height, weight, strength, aerobic power, anaerobic power).

### Age and Gender

**Age** is recorded to the closest year (y), except when it may be important to record to the closest one-tenth of a year. For example, if someone turned 32 y of age four months ago, the age might be recorded as 32.3 y.

**Gender** for a person is abbreviated as M (male) or F (female). For a group of adults (18 years old and above), the recommended group designation is M (men) and W (women).[1] But, if there are minors (under 18 y of age), the group designation is male or female, not men or women.

### Height (Stature) and Body Weight (Mass)

In the field of anthropometry (defined as the measurement of humans), the term *stature,* derived from *statue,* is used to describe the standing height of a human (as if a statue). As noted earlier, although *stature* is the appropriate term to use in a scientific context when describing the anthropometric characteristics of the participants of a study, *height* is used throughout most of this laboratory manual because it is the more common term.

Mass, as noted in Chapter 2, is synonymous with weight when measured under the same acceleration of gravity. Because most measurements are assumed to be taken on earth, these two terms can be used interchangeably in most cases. The terms *mass, body mass,* and *lean body mass* are used in scientific publications, especially with reference to describing the body composition of the study participants. The terms *weight* and *body weight*, however, are also acceptable and again, because of their more common usage, are the terms of choice in this laboratory manual. The body mass and body weight of a person use the same unit of measure—the kilogram (kg). In Chapter 4, we will see that body weight can also be used as a measure of force, for the purpose of calculating work and power, in which case it is expressed in newtons (N).

#### *Measurement Precision*

The technician records height to the nearest tenth of a centimeter (0.1 cm; 1 mm) if the height scale (stadiometer; anthropometer) has such graduations (markings). If the measurement device is marked only in inches and the graduations are ¼ in. or ½ in., the technician records the inches to the closest ¼ in. or ½ in., respectively. Then