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Exercise Physiology

Laboratory Manual

William C. Beam
Gene M. Adams

Mc Graw Hill Education

Eighth Edition

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PREFACE

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

The Eighth Edition

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

Features of the seventh edition remaining include:

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

Significant changes made to the eighth edition include the following:

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

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

Content and Organization

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

Part IV, Aerobic Fitness, includes chapters on aerobic walking, jogging, running, stepping, and cycling and on the direct measurement of maximal oxygen consumption ($\dot{V}O_2max$). 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, includes chapters on resting lung volumes and exercise ventilation. Emphasis is placed on the measurement of lung function and identification of any restrictive or obstructive lung conditions the participant may possess at rest or during exercise. Part VII, Flexibility, includes a description and discussion of the measurement of lower body flexibility. Part VIII, Body Composition, includes chapters on assessing body composition by means of body mass index, girth, skinfolds, and hydrostatic weighing.

Supplements That Support Instructors

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

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

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

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

Philosophical Approach

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

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

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

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

Acknowledgments

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

From William Beam:

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

From Gene Adams:

My first teacher, Dr. Larry Morehouse, introduced me to exercise physiology and set the framework for my future knowledge in this field. My second teacher, Dr. Herbert deVries, contributed to my technical and research skills, while enhancing my knowledge and encouraging my involvement in the profession. My role model, Dr. Fred Kasch, showed me how to apply what I knew to the general public and to students. I am grateful to my colleagues from all parts of the country who contributed their encouragement and ideas. A big thank you goes to my wife, Janet, the illustrator for this manual, and to my son, Mannie, and my daughter, Shawn, who served as my wife's models.

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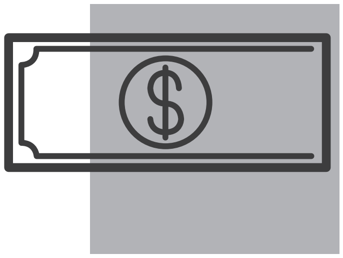

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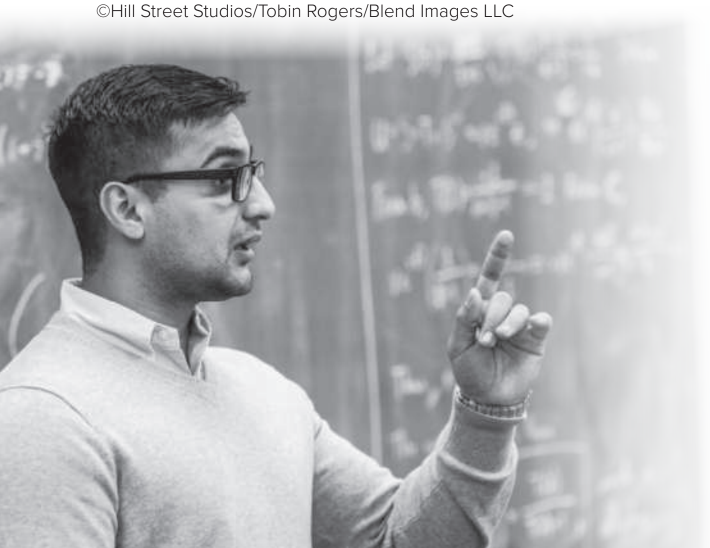

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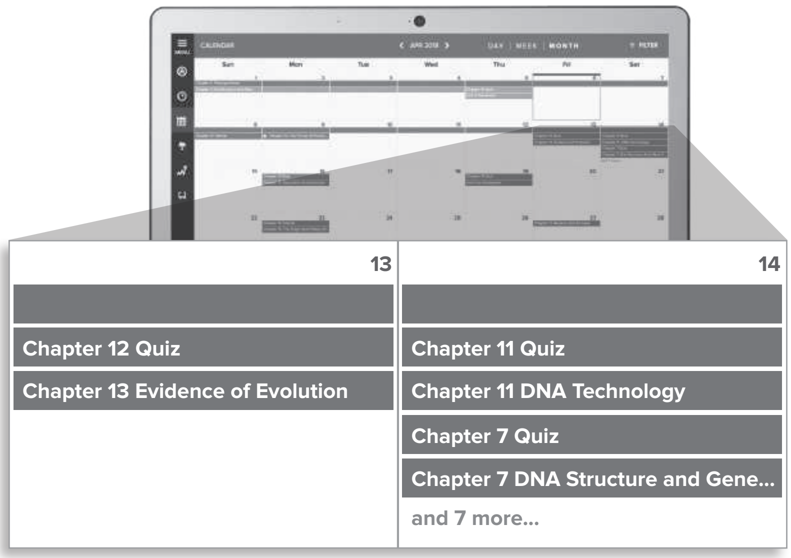

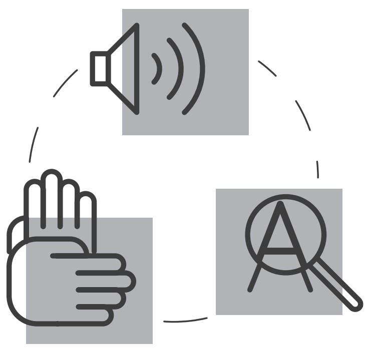

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CHAPTER 1

Introduction and Terminology

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

Components of Fitness

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

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

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

Muscular Strength and Endurance

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

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

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

Anaerobic Fitness

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

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

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

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

Aerobic Fitness

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

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

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

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_2max 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.

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

Energy

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

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

$$\text{Energy}\,(kJ\cdot min^{-1}) = \text{Oxygen uptake}\,(L\cdot min^{-1}) * 21.1\,kJ\cdot L^{-1} \qquad \text{Eq. 1.3b}$$

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).

$$\text{Speed} = \text{Distance}\,(D)\ /\ \text{Time}\,(t) \qquad \text{Eq. 1.4a}$$

$$\text{Velocity} = \text{Displacement}\,(d)\ /\ \text{Time}\,(t) \qquad \text{Eq. 1.4b}$$

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 2π 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.

$$\text{Torque}\,(\tau) = \text{Force}\,(F) * \text{Lever arm length}\,(D) \qquad \text{Eq. 1.5}$$

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[31] 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.

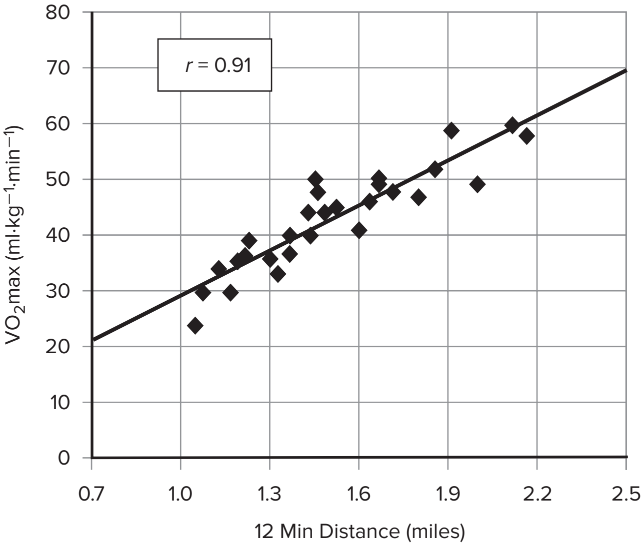

Figure 1.1 Data from Chapter 14 demonstrating the linear relationship between distance run/walked in 12 min and maximal oxygen uptake. The high, positive correlation coefficient (*r* = 0.91) indicates a strong, direct relationship between the two variables.

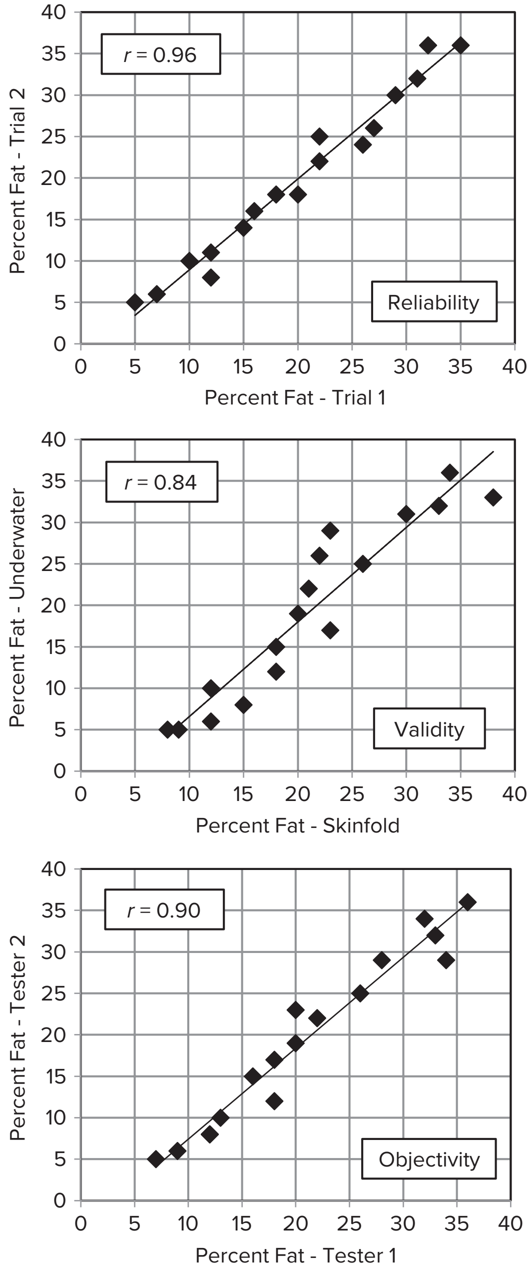

Figure 1.2 Demonstration of reliability (comparing 2 trials done by the same tester), validity (comparing 2 different methods), and objectivity (comparing 2 different testers) of measuring percent body fat.

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 ≥.80

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

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

Standards 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[14]	81–100	Excellent
	61–80	Above average
	41–60	Average
	21–40	Below average
	1–20	Poor
YMCA[15]	90–100	Well above average
	70–89	Above average
	50–69	Average
	30–49	Below average
	10–29	Well below average
Functional Fitness Test[27]	76–100	Above average
	25–75	Average
	1–24	Below average

Sources: Based on Fitness and Amateur Sport Canada (1987)[14]; 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.

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.

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?

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, Myanmar (also known as Burma), and Liberia—have not officially adopted, or are not fully committed to, the metric system.[6] Therefore, with apologies to Myanmar 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 "60kg," 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·min^{-1}, unless this is impractical for certain computers. 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·kg^{-1}·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·m·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.

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.

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)

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 5.0 (Eq. 2.1a) or by 21.1 (Eq. 2.1b), respectively.

$$\text{Energy (caloric) expenditure (kcal)} = \text{Oxygen uptake } (L \cdot min^{-1}) * 5.0 \qquad \text{Eq. 2.1a}$$

$$\text{Energy (Kilojoule) expenditure (kJ)} = \text{Oxygen uptake } (L \cdot min^{-1}) * 21.1 \qquad \text{Eq. 2.1b}$$

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.

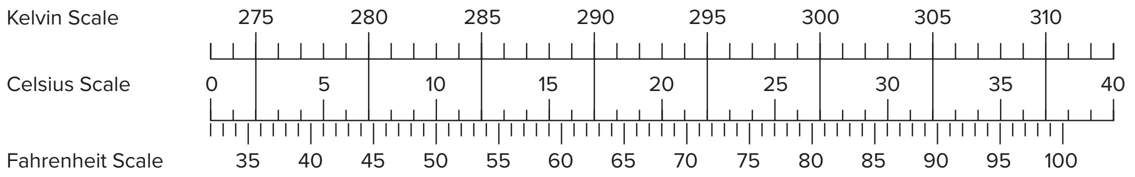

Figure 2.1 Conversion of temperature between different scales.

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: $hPa = mm\ Hg * 1.3332$ Eq. 2.4a

hPa to mm Hg: $mm\ Hg = hPa * 0.750$ Eq. 2.4b

in. Hg to hPa: $hPa = in.\ Hg * 33.867$ 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)
1 g = 1000 mg = 0.0022 lb = 0.0352 oz
1 kg = 1000 g = 2.2046 lb = 35.2736 oz
1 lb = 16 oz = 453.59 g = 0.4536 kg
1 oz = 28.3495 g
Gravity constant (g) = 9.81 $m{\cdot}s^{-2}$ = 32.2 $ft{\cdot}s^{-2}$

Length and Height (meter; m)
1 m = 1000 mm = 1.0936 yd = 3.281 ft = 39.37 in.
1 km = 1000 m = 0.6214 mile = 1093.6 yd
1 mile = 1.6094 km = 1609.4 m
1 yd = 3 ft = 0.9144 m = 91.44 cm
1 ft = 12 in. = 0.3048 m = 30.48 cm
1 in. = 25.4 mm = 2.54 cm = 0.0254 m

Force (newton; N)
1 N = 0.1020 kg = 0.2248 lb
1 kg = 1000 g = 2.2046 lb = 9.8067 N
1 lb = 0.4536 kg = 453.59 g = 4.4482 N

Work (joule; J)
1 J = 1 N·m = 0.1020 kg·m = 0.7375 ft·lb
1 kg·m = 9.8067 J = 9.8067 N·m = 7.2307 ft·lb
1 ft·lb = 1.3559 J = 1.3559 N·m = 0.1393 kg·m

Power (watt; W)
1 W = 1 $J{\cdot}s^{-1}$ = 1 $N{\cdot}m{\cdot}s^{-1}$ = 0.1020 $kg{\cdot}m{\cdot}s^{-1}$
1 W = 60 $J{\cdot}min^{-1}$ = 60 $N{\cdot}m{\cdot}min^{-1}$ = 6.1183 $kg{\cdot}m{\cdot}min^{-1}$
1 $N{\cdot}m{\cdot}min^{-1}$ = 0.0167 W = 0.1020 $kg{\cdot}m{\cdot}min^{-1}$
1 $kg{\cdot}m{\cdot}min^{-1}$ = 0.1634 W = 9.8067 $N{\cdot}m{\cdot}min^{-1}$
1 kW = 1000 W = 1.3410 horsepower (hp)

Energy (kilojoule; kJ)
1 kJ = 1000 J = 0.2389 kcal
1 kcal = 4.1858 kJ = 4186 J
1 kcal = 426.85 kg·m (*at 100 % efficiency*)
1 L VO_2 ≈ 21.1 kJ ≈ 5.0 kcal (*at RER = 0.96*)

Speed and Velocity ($meter{\cdot}second^{-1}$; $m{\cdot}s^{-1}$)
1 $m{\cdot}s^{-1}$ = 2.2371 $mi{\cdot}h^{-1}$ (mph) = 3.2808 $ft{\cdot}s^{-1}$
1 $m{\cdot}min^{-1}$ = 0.0373 mph = 3.2808 $ft{\cdot}min^{-1}$
1 $km{\cdot}h^{-1}$ = 1000 $m{\cdot}h^{-1}$ = 0.6215 mph
1 mph = 1.6093 $km{\cdot}h^{-1}$ = 26.822 $m{\cdot}min^{-1}$ = 0.4470 $m{\cdot}s^{-1}$ = 1.4667 $ft{\cdot}s^{-1}$

Angular Velocity ($radian{\cdot}second^{-1}$; $rad{\cdot}s^{-1}$)
2 π rad (~ 6.2832 rad) = 360° (*1 full circle*)
1 rad = 360° / 2π = 57.296°
1 $rad{\cdot}s^{-1}$ = 57.296$°{\cdot}s^{-1}$
1$°{\cdot}s^{-1}$ = 0.0175 $rad{\cdot}s^{-1}$

Torque (newton meter; N·m)
1 N·m = 0.1020 kg·m = 0.7375 ft·lb
1 kg·m = 9.8067 N·m = 7.2307 ft·lb
1 ft·lb = 1.3559 N·m = 0.1393 kg·m

Volume (liter; L)
1 L = 1000 ml = 1.0567 qt = 33.81 fluid ounce (fl oz)
1 qt = 32 fl oz = 0.9464 L = 946.4 ml
1 ml = 0.0338 fl oz
1 fl oz = 0.0313 qt = 0.0296 L = 29.574 ml
1 cup = 8 fl oz = 236.6 ml

Pressure (pascal; Pa)
1 pascal (Pa) = 1 $N{\cdot}m^{-2}$ = 0.00015 $lb{\cdot}in.^{-2}$
1 hectopascal (hPa) = 100 Pa = 0.1 kilopascal (kPa)
1 hPa = 1 millibar (mbar) = 0.750 torr = 0.750 mm Hg = 0.0145 $lb{\cdot}in^{-2}$
1 torr = 1 mm Hg = 1.3332 hPa = 1.3332 mbar
1 atmosphere (atm) = 1013 hPa = 1013 mbar = 760 torr = 760 mm Hg = 29.92 in. Hg = 14.70 $lb{\cdot}in.^{-2}$

Temperature (kelvin; K)
°C to K: K = (°C + 273)
K to °C: °C = (K – 273)
°C to °F: °F = (°C * 1.8) + 32
°F to °C: °C = (°F – 32) / 1.8

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., $m{\cdot}kg{\cdot}s^2$, $m^2{\cdot}kg{\cdot}s^{-3}$, $m{\cdot}s^{-1}$, 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 $m{\cdot}kg{\cdot}s^{-2}$, or expressing pressure in pascals (Pa) instead of $m^{-1}{\cdot}kg{\cdot}s^{-2}$.

The metric system is also easier when it comes to measuring small or large quantities. For example, one meter (1 m) 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** * (4.4482 N / 1 lb) = **672 N** Eq. 2.6a

Weight, X N = **151 lb** * (1 N / 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.

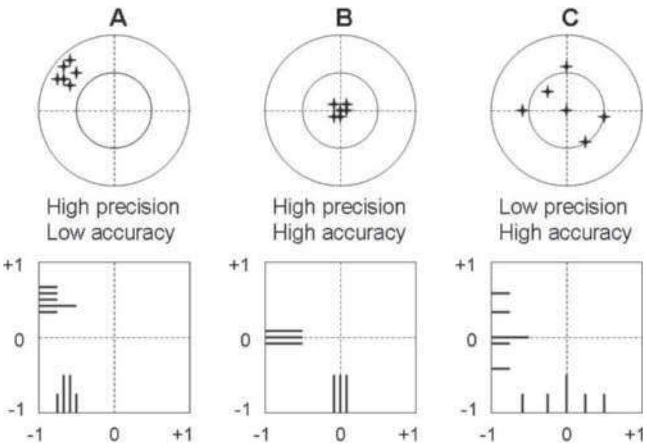

Figure 2.2 Demonstration of precision and accuracy. The upper portion of the figure shows six shots taken at each of three targets. The lower portion is the frequency with which each shot hit the target, with 0 in both directions (X and Y) being a "perfect" shot.

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 customary 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** ∗ (9.8067 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 / 6.1183 kg·m·min^{-1}) = **84.2 W** Eq. 2.8c

Energy, X kJ = **125 kcal** ∗ (4.1858 kJ / 1 kcal)
= **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}**
∗ (1hPa / 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 1609.4 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).

$$\text{X m·s}^{-1} = \mathbf{55}\ \cancel{\text{mph}} \ast \frac{0.4470\ \text{m·s}^{-1}}{1\ \cancel{\text{mph}}} = \mathbf{25}\ \text{m·s}^{-1} \qquad \text{Eq. 2.10a}$$

$$\text{X m·s}^{-1} = \frac{\mathbf{55}\ \cancel{\text{mi}}}{\cancel{\text{h}}} \ast \frac{1609.4\ \text{m}}{1\ \cancel{\text{mi}}} \ast \frac{1\ \cancel{\text{h}}}{60\ \cancel{\text{min}}} \ast \frac{1\ \cancel{\text{min}}}{60\ \text{s}} = \mathbf{25}\ \text{m·s}^{-1} \qquad \text{Eq. 2.10a}$$

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,

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?

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 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 Units of Measure **Homework**

Name: ______________________ Date: __________ Score: ________

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 =	**1014**	kJ	*	______	= ______	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 Units of Measure — Lab Results

Name: ______________________ Date: __________ Score: ______

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 meaured 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**	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	kg, lb, N	Range	____	Precision	____		
Power	Power =	____	W *	____		=	____	$kg{\cdot}m{\cdot}min^{-1}$
Cycle ergometer	Units	W, $kg{\cdot}m{\cdot}min^{-1}$	Range	____	Precision	____		
Speed	Speed =	____	mph *	____		=	____	$km{\cdot}h^{-1}$
Treadmill	Units	mph, $km{\cdot}h^{-1}$	Range	____	Precision	____		
Volume	Volume =	____	L *	____		=	____	ml
Spirometer	Units	L, ml	Range	____	Precision	____		
Pressure	Pressure =	____	mm Hg *	____		=	____	torr
Sphygmomanometer	Units	mm Hg, torr	Range	____	Precision	____		
Temperature	Temperature =	____	°F =	____		=	____	K
Thermometer	Units	°F, °C, K	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 the inch value is converted and recorded to the appropriately rounded centimeter or decimal centimeter.

The main considerations in rounding off numbers are conventionality, consistency of the significant digits, and precision of the measurement. The appropriate conventionality guide is that of the International System (SI).[15] SI recommends using the "5 rule" when reducing a certain number of digits. Fortunately, most Americans are familiar with this rule: "If the digits to be discarded begin with a digit less than 5, the digit preceding the 5 is not changed." For example, the number 7.44 changed to a two-digit number would become 7.4; changed to a one-digit number, it would become 7 (but not 7.0). Conversely, if the discarded digit or digits begin with a number greater than or equal to 5, then the digit preceding the 5 is increased by 1. For example, 167.66 cm becomes 167.7 cm as a four-digit number and becomes 168 as a three-digit number.

The degree of precision sought in a measure or mathematical calculation depends upon the purposes of the measurement and the precision of the instrument. In the United States the height of a person is often stated to the closest ½ in. (1.27 cm) or ¼ in. (0.64 cm), depending upon the accuracy of the stadiometer. Thus, when the mean *(M)* height is calculated from the heights of several persons, it should be rounded off either to the closest ½ in. or ¼ in., respectively. If converting the inches to centimeters, both the ½ in. (0.5 in.) and ¼ in. (0.25 in.) values should not be rounded to the closest tenth centimeter because the stadiometer does not justify such precision. The closest 0.5 cm would be a justifiably rounded number for the ¼ in. scale and to the closest centimeter for the ½ in. scale. Rounding off to the closest *tenth* centimeter provides unwarranted and false precision. However, if the purpose of the investigators is to detect the change in height in persons from morning to evening, then they should choose a more precise stadiometer. The use of a stadiometer with graduations in tenths of a centimeter allows measurement of height to the closest 0.1 cm (1 mm).

BOX 3.1 Accuracy of Height and Body Weight Measures

Height

The test-retest reliability of height (stature) measurements is consistently high. A review article on anthropometric measurement error reported a mean reliability coefficient (*R*) for the measurement of height of .98 with a range of .93–.99.[16]

Height measurements may differ throughout the day due to compression of the spine.[16] Studies have shown height decreases of 6 mm to 8.8 mm later in the day.[3,7] Conversely, lying supine (for an average of 49 min) later in the day resulted in a 5 mm increase in height.[4]

Body Weight

The test-retest reliability of body weight (mass) measurements is also high. Range of reported reliability coefficients for the measurement of body weight is .95–1.00 with a mean of .98.[16]

Self-Reported Height and Weight

Generally speaking, the direct measurement of height and weight is preferred to the use of self-reported values when possible. Although highly correlated with actual height ($r = .82–.91$) and weight ($r = .87–.94$),[14] self-reported values differ significantly from the actual values. High school students[2] ($n = 4619$) overestimated height by 6.9 cm and underestimated weight by 1.6 kg. Adult males[12,13] overestimated height by 0.38–1.23 cm and underestimated weight by 1.40–1.85 kg, while adult females[12,13] overestimated height by 0.38–0.40 cm and underestimated weight by 0.54–0.85 kg.

Older Adults

The use of self-reported height and weight has limitations in older adults (over 60 years).[6] In research studies and clinical settings involving older adults, failure to directly measure height and weight can result in substantial error. Special consideration should also be given to diurnal variations in height in older adults if spinal osteoporosis is a concern.[4]

Environmental Conditions

Although environmental or meteorological conditions have no known effect on height or weight, they can affect other variables measured in the exercise physiology laboratory. It is recommended that the technician practice recording room temperature, barometric pressure and relative humidity. These laboratory or environmental conditions are most important when measuring air volumes (e.g. vital capacity, pulmonary ventilation, etc.). The conversion between ambient (ATPS), body (BTPS) and standard (STPD) conditions using these environmental data is discussed in Chapters 15, 20 and 21.

General Measurement Procedures

It is recommended that students test other students rather than a student testing him- or herself. Although this can take more time, it mimics typical research procedures and gives students, who would be referred to as "technicians," or "testers," in this case, the chance to practice in their personal relationship with the participant. As an example, technicians (students) should call participants (other students) by their names and thank them for their cooperation and effort.

The methods sections in this manual usually include two major phases—preparations and procedures. Three items are usually included in the procedures phase—the technician's steps for administering the test, the calculations and conversions, and the recording of the data onto the forms. Box 3.1 discusses the accuracy of height and body weight measures.

Methods

Height (Stature) Method

Height is a basic variable that is routinely measured in nearly all laboratories. Its accurate and standardized measurement should be given serious attention. The purposes for measuring height include (1) to familiarize students with standardized height measurements; (2) to characterize or describe the participant; (3) to relate the participant's height to norms or standards; (4) to relate body weight with height; (5) to relate height with growth or nutritional status; and (6) to relate height and body weight with risk of chronic diseases or conditions.

Height can be measured on a platform scale (sometimes also referred to as a physician's scale) equipped with a stadiometer (*stadio* = stature; *meter* = measure), as shown in Figure 3.1. The stadiometer includes a hinged lever that the technician can swing upward to a 90° angle and place on the crown of the participant's head to measure height. Stadiometers (especially newer ones) usually have both inch and centimeter graduations. Wall-mounted stadiometers, separate of a weight scale, are also available (e.g., Seca, Harpenden). These devices are often preferred to the stadiometer connected to the platform scale, because the mechanism allows for a smoother, more accurate measure of height. A stadiometer can also be improvised by attaching a measuring tape to a wall. The participant stands with the back against the wall, and any right-angled device is placed against the crown of the head and the measuring tape. It may be helpful to have a stool available for the technician to stand on to measure tall persons. The following procedures help to standardize and enhance the accuracy of height measurements.

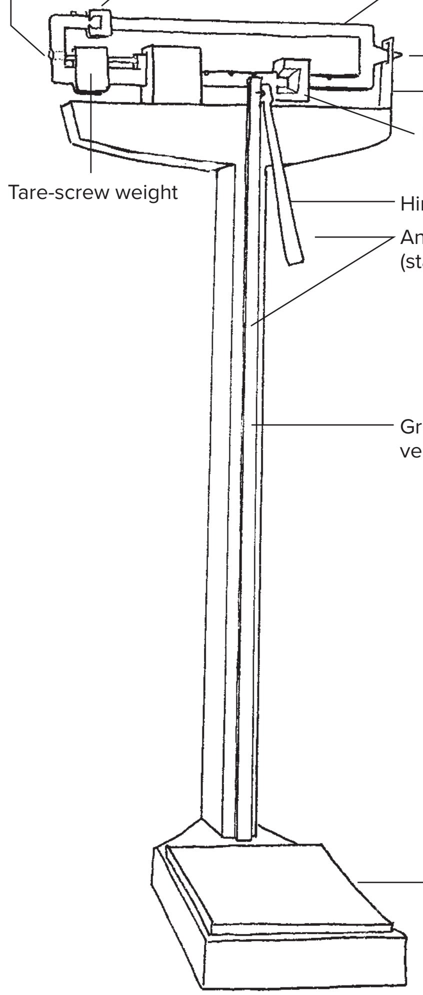

Figure 3.1 The platform scale is an instrument for body weight (mass) and height (stature). The anthropometer (stadiometer) with the sliding vertical bar and hinged horizontal head lever is the portion of the platform scale that measures height.

Preparation by the Technician to Measure Height

1. If using the platform-beam scale, check its accuracy by confirming the distance from the platform base to the first graduated measure on the stadiometer.
2. Complete Form 3.2 with the prior basic data information (name, date, time, age, and gender).
3. Ask the participant to remove shoes; removing socks is also preferred, but thin socks may remain.
4. The hair should be worn down and low to the head. It may be necessary to ask the participant to remove accessories from the hair so that it may be worn down.

Procedures for Measuring Height

1. The participant steps onto the platform scale and turns away from the stadiometer. The technician asks the participant to lower the head in order to clear the swing of the hinged lever to a horizontal position. If using a wall-mounted stadiometer, the participant stands facing away from the wall, with heels, scapulae, and buttocks in contact with the wall. Some persons will not be able to maintain a natural stance if the posterior of the head is also touching the wall.[3]
2. The participant stands as tall as possible with heels together and feet evenly balanced at an angle of approximately 60°, using the medial borders (inside) of the feet and the wall as the reference lines. For example, a 90° angle would indicate that the feet were pointed directly forward.
3. The participant tucks the chin to bring the head into a position that horizontally aligns the lowest point of the orbit of the eye with the opening of the ear canal.
4. As the participant inhales deeply and maintains the designated position, the technician moves the hinged lever of the platform scale stadiometer into contact with the crown of the head. It may be necessary to "compress"

the participant's hair so that the lever contacts the head. If a stadiometer is not available, and height is being measured against a wall, the technician places one edge of the right-angled object against the wall and places the other edge on top of the participant's head.

5. The technician records height on Form 3.2 to the highest precision possible depending on the measurement device. If using a stadiometer, it should be possible to record height to the nearest tenth centimeter (0.1 cm). If using a less precise instrument, record height to the closest ½ in. or ¼ in., whichever is possible.
6. The technician (if necessary) converts the height from inches to centimeters and then records it on Form 3.2 to the appropriately rounded centimeter.

Body Weight (Mass) Method

Body mass is probably the most measured variable in exercise physiology laboratories. This basic variable is factored into many of the other variables described in this laboratory manual; hence, its importance cannot be overstated. Body weight can fluctuate significantly based on the amount of food and water consumed throughout the course of a day. It is best, especially if tracking body weight longitudinally, that it is measured at the same time each day, preferably in the morning. Ideally, body weight would be measured nude in the morning following a 12-hour fast and following evacuation of all urine and feces from the body. This could be considered a "true" body weight. When longitudinal body weights are measured on the same person at different times of day they could vary by several kilograms just due to varying levels of food intake or hydration status.

Participants can be weighed in the attire that corresponds to the reference source. For example, if the reference source for comparison allowed 0.3 kg of clothing, such as underwear, shirt, and shorts, dress, or pants, then the person may be weighed in such attire. In some cases, especially when measuring body composition, nude weight is preferred. Because of the impracticality of obtaining nude weight, some researchers derive nude weight by weighing the clothes in which the participant is weighed and then subtracting the weight of the clothing from the clothed body weight. If a person wears only a nylon swimsuit or a disposable paper gown, it may be deemed as nude weight. The exercise-clothed weight should be used for the calculation of work or power when the participants are lifting their own body weight, such as in bench stepping, uphill walking, or uphill running. The following methods are helpful when measuring a participant's body weight.

Preparation by the Technician to Measure Weight

1. Calibrate the weighing scale, if it has not been calibrated within a month (Box 3.2).
2. Record the acquired basic data onto Form 3.2, including the participant's name, date, time, age, gender, and meteorological data.

BOX 3.2 Example of Calibration Procedures for the Platform Scale

Zero Calibration

1. Set both moveable beam-weights of the scale to the zero positions.
2. Observe the position of the pointer; it should come to rest in midair between the top and bottom of the pointer window.
3. If necessary, balance the pointer in this midair position by using a screwdriver to adjust the tare-screw weight of the platform scale. Turning the tare screw clockwise moves the tare-screw weight toward the screw's head, thus lifting the pointer higher in the pointer window.

High-Point Calibration

1. Set the beam-weights to the highest position for which you have calibration weights or to the position of the highest expected body weight of your participants. Typical platform scales cannot read body weights above 159 kg (350 lb). Ideally, if you have 350 lb of certified weights, place them on the scale. But, if you have only 100 kg (220.5 lb to closest 0.1 lb) certified weights, or weights that you have "certified" on a precision scale, set them on the scale and adjust the beam-weights accordingly. For example, set the heavy beam-weight to 200 lb and set the light beam-weight to 20.5 lb.
2. Observe the position of the pointer. If it is balanced in midposition in the pointer window, the scale is accurate at body weights near the high-point range.
3. If the pointer is above the balanced point, adjust the light beam-weight, if necessary, to the pointer's midair position.
4. Record any discrepancy between the original set position and the final balanced position.
5. If needed, derive a correction factor for the high-point readings. For example, if 120 kg of "certified" high-point weights showed 121 kg on the scale, subtract 1 kg from those persons' body weights that were between 110 kg and 130 kg (range chosen arbitrarily).

Midpoint Calibration

1. Estimate the average body weight of the participants.
2. Place "certified" weights on the scale that come close to the estimated participants' average weight.
3. Balance the pointer to the midair position. If it is already balanced, the scale is accurate near the midpoint position of the pound or kilogram scale.
4. If the pointer is not in the midair position, adjust the light beam-weight to the balanced position.
5. Record any discrepancy between the original set position and the final midair position.
6. If needed, derive a correction factor for midpoint readings or readjust the tare-screw weight to the pointer's midair position. Unfortunately, this will change the zero point, thus distorting low-range body masses.

3. Ask the participant to remove shoes, socks, jewelry, and accessories, empty all pockets, and remove as much clothing as feasible.
4. Weigh the person's "weigh-in clothing" and record onto Form 3.2 (optional).

Procedures for Measuring Body Weight

1. The participant stands on and faces the scale.
2. The technician places the heavy beam-weight (lower lever) to the estimated graduation mark first, followed by the light beam-weight (upper lever). The light beam-weight is moved slowly to balance the pointer in the midair position within the window of the scale. If the pointer cannot be balanced, the heavy beam weight must be readjusted. If an electronic digital scale is being used, the technician simply reads the body weight on the indicator of the scale.
3. The technician records body weight on Form 3.2 to the highest precision possible depending on the measurement device. If using a platform scale, it should be possible to record body weight to the nearest ½ or ¼ lb. If using a more precise instrument, record body weight to the closest 0.1 kg (or to the maximum precision the instrument allows).
4. The technician (if necessary) converts the body weight from pounds to kilograms and then records it on Form 3.2 to the appropriately rounded kilogram.
5. The technician assists the participant off the scale, thanks the participant, and reminds the participant of any jewelry, accessories, or pocket contents that may have been removed.

Environmental Data

Environmental or meteorological data are frequently monitored using a simple electronic weather station. Such a device provides data for time of day, room temperature (typically in °C and °F), barometric pressure (typically in mm Hg and in. Hg), and relative humidity (%). Some laboratories are equipped with separate pieces of equipment including a thermometer for measuring temperature, a barometer (either mercurial or analog) for measuring barometric pressure, and a hygrometer (either digital or analog) for measuring relative humidity.

Procedures for Collecting Environmental Data

1. The technician records lab/room temperature (°C) on Form 3.2 to the highest precision possible depending on the measurement device (weather station or thermometer).
2. The technician records barometric pressure (mm Hg) on Form 3.2 to the highest precision possible depending on the measurement device (weather station or barometer).
3. The technician records relative humidity (%) on Form 3.2 to the highest precision possible depending on the measurement device (weather station or hygrometer).

Results and Discussion

The results section of a scientific report or study simply presents the findings in the text, tables, and figures. In the exercise physiology classroom, the results of the measurements are also recorded on the individual data collection form (e.g., Form 3.2). Frequently the results of an entire group are of interest. Group results typically include the mean *(M),* standard deviation *(SD),* and range of scores—that is, the lowest (minimum) to the highest (maximum) score.

The discussion section of a scientific report provides the reader with an interpretation of the results or measured values. An evaluation of the individual's height or body weight and the average of the group can be made by referring to the appropriate comparative data.

This particular discussion focuses on the effect of age, race/ethnicity, and time of day on height or body weight, and looks at how the height and body weight of the average American has changed over the years.

Effect of Age

The height and weight of the average American is of interest with regard to growth, nutritional status, risk of chronic disease, the effect of aging, and other public health and research concerns. A recent publication[5] reviewed height and weight data from national surveys conducted between 2011 and 2014. The mean or average height and weight by gender and age group are seen in Table 3.1 and Table 3.2. The average American adult male has a height of 175.7 cm (69.2 in.) and a weight of 88.8 kg (195.7 lb), with the average female having a height of 161.8 cm (63.7 in.) and body weight of 76.4 kg (168.5 lb). It can be seen in both genders that height reaches a peak by 39 years of age. Height then diminishes by about 1 cm per decade, resulting in a height loss of about 4–5 cm by the age of 79. Body weight appears to reach a peak at about age 40–49 years in men and slightly later at 50–59 years in women, with a subsequent decline in the later years, especially after 70 years of age. Caution should always be used, however, in interpreting any trends in this way since these are *cross-sectional data* and not *longitudinal data*. Cross-sectional data are collected at the *same time* on *different participants* in each category (in this case different age categories), whereas longitudinal data are collected on the *same participants* over the *entire range* of interest (in this case that would mean measuring the same participants from age 6 through age 79).[5]

For comparative purposes, Table 3.3 provides descriptive categories for weight derived from percentiles. Body weight is described as "much higher than average" (< 95th percentile), "higher than average" (75th–95th percentile), "average" (25th–75th percentile), "lower than average" (5th–24th percentile), and "much lower than average"

Table 3.1	Average Height (cm; in.) by Gender and Age Group (United States, 2011–2014)					
	Males	Height ($M \pm SEM$)		Females	Height ($M \pm SEM$)	
Age Group	*N*	cm	in.	*N*	cm	in.
6 years	246	120.0 ± 0.49	47.2 ± 0.19	216	118.7 ± 0.43	46.7 ± 0.17
10 years	207	143.0 ± 0.67	56.3 ± 0.26	187	144.3 ± 0.77	56.8 ± 0.30
14 years	184	169.4 ± 0.78	66.7 ± 0.31	169	160.3 ± 0.54	63.1 ± 0.21
18 years	160	175.6 ± 0.85	69.1 ± 0.33	154	161.7 ± 0.57	63.6 ± 0.22
20–29 years	937	175.7 ± 0.21	69.4 ± 0.10	928	162.9 ± 0.30	64.1 ± 0.12
30–39 years	914	176.6 ± 0.30	69.5 ± 0.12	957	163.4 ± 0.30	64.3 ± 0.12
40–49 years	872	176.2 ± 0.42	69.4 ± 0.17	987	162.9 ± 0.31	64.1 ± 0.12
50–59 years	852	176.0 ± 0.50	69.3 ± 0.20	924	161.9 ± 0.37	63.7 ± 0.15
60–69 years	877	175.3 ± 0.46	69.0 ± 0.18	888	160.5 ± 0.37	63.2 ± 0.15
70–79 years	486	173.0 ± 0.32	68.1 ± 0.12	527	159.3 ± 0.35	62.7 ± 0.14
Total Mean	**5 232**	**175.7 ± 0.21**	**69.2 ± 0.08**	**5 547**	**161.8 ± 0.21**	**63.7 ± 0.08**

Source: Fryar, Gu, Ogden, & Flegal (2016).[5]

Table 3.2	Average Weight (kg; lb) by Gender and Age Group (United States, 2011–2014)					
	Males	Weight ($M \pm SEM$)		Females	Weight ($M \pm SEM$)	
Age Group	*N*	kg	lb	*N*	kg	lb
6 years old	247	23.9 ± 0.39	52.8 ± 0.85	216	23.8 ± 0.48	52.4 ± 1.05
10 years old	207	40.3 ± 1.25	88.7 ± 2.76	187	41.3 ± 1.27	90.9 ± 2.80
14 years old	184	65.9 ± 1.83	145.2 ± 4.03	169	58.6 ± 1.52	131.4 ± 3.35
18 years old	160	81.4 ± 3.22	179.4 ± 7.09	154	67.2 ± 2.59	148.2 ± 5.72
20–29 years old	936	84.7 ± 1.18	186.8 ± 2.60	853	73.4 ± 0.85	161.8 ± 1.88
30–39 years old	914	90.2 ± 0.78	196.8 ± 1.73	915	78.4 ± 0.87	172.9 ± 1.92
40–49 years old	872	91.5 ± 0.73	201.7 ± 1.60	979	78.5 ± 1.00	173.1 ± 2.21
50–59 years old	854	90.5 ± 0.92	199.5 ± 2.03	923	79.1 ± 1.05	174.4 ± 2.31
60–69 years old	874	90.6 ± 1.37	199.7 ± 3.02	889	76.6± 0.90	168.8 ± 1.98
70–79 years old	486	85.8 ± 0.92	189.3 ± 2.03	527	75.2 ± 0.94	165.8 ± 2.06
Mean ± *SEM*[a]	**5 236**	**88.8 ± 0.43**	**195.7 ± 0.94**	**5 425**	**76.4 ± 0.42**	**168.5 ± 0.92**

[a]*Note:* Mean of all persons 20–79 years old. *Source:* Fryar, Gu, Ogden, & Flegal (2016).[5]

Table 3.3	Category for Weight (kg; lb) by Gender and Age Group (United States, 2011–2014)					
Men	20–29 years (*N* = 936)		30–39 years (*N* = 914)		40–49 years (*N* = 872)	
Category (*Percentile*)	kg	lb	kg	lb	kg	lb
Much higher than ave (> *95th*)	> 127.4	> 281	> 127.9	> 282	> 126.6	> 279
Higher than ave (*75th–95th*)	94.7–127.4	210–281	100.4–127.9	222–282	101.0–126.6	223–279
Average (*25th–75th percentile*)	69.5–94.6	154–209	76.3–100.3	169–221	78.0–100.9	173–222
Lower than ave (*5th–25th*)	57.3–69.4	126–153	63.6–76.2	140–168	66.3–77.9	146–172
Much lower than ave (< 5th)	< 57.3	< 126	< 63.6	< 140	< 66.3	< 146
Mean ± *SEM*	**84.7 ± 1.2**	**186.8 ± 2.6**	**90.2 ± 0.8**	**198.8 ± 1.7**	**91.5 ± 0.7**	**201.7 ± 1.8**
Women	20–29 years (*N* = 853)		30–39 years (*N* = 915)		40–49 years (*N* = 979)	
Category (*Percentile*)	kg	lb	kg	lb	kg	lb
Much higher than ave (> *95th*)	> 115.8	> 255	> 122.1	> 269	> 118.5	> 261
Higher than ave (*75th–95th*)	83.8–115.8	186–255	89.0–122.1	197–269	89.4–118.5	198–261
Average (*25th–75th percentile*)	58.5–83.7	130–185	62.6–88.9	138–196	63.1–89.3	140–197
Lower than ave (*5th-25th*)	48.6–58.4	107–129	52.1–62.5	115–138	52.5–63.0	116–139
Much lower than ave (< *5th*)	< 48.6	< 107	< 52.1	< 115	< 52.5	< 116
Mean ± *SEM*	**73.4 ± 0.9**	**166.1 ± 1.9**	**78.4 ± 0.9**	**172.9 ± 1.9**	**78.5 ± 1.0**	**173.1 ± 2.2**

Source: Fryar, Gu, Ogden, & Flegal (2016).[5]

(< 5th percentile). Because of the effect of age on body weight, the categories are further subdivided by age group: 20–29 years, 30–39 years, and 40–49 years. This particular age range (20–49 years) is given special attention, as it was chosen to represent "young" adults, thinking that they would be the predominant users of this laboratory manual. However, data representing younger and older age groups are also included in numerous chapters throughout this laboratory manual whenever representative data sets were available in the research literature. No similar table is provided for height, as there are only minimal differences in height throughout this particular age range (20–49 years).[5]

Effect of Race/Ethnicity

A search for height and body weight data in the Unites States by race or ethnicity reveals good normative data for four groups: white (Caucasian American), black (African American), Hispanic (including Mexican American), and Asian (Asian American).[5] Large representative data sets for other racial and ethnic groups possibly exist, but no sets with the same validity representing other ethnicities living in the United States were found. Table 3.4 and Table 3.5 provide categories for height and weight, respectively, for the four racial/ethnic groups living in the United States. The average heights for white men (177.1 cm) and for black men (176.4 cm) both

Table 3.4 Category for Height (cm) by Gender and Race (United States, 2011–2014)

Men Category (*Percentile*)	Total *N* = 5 232	White *N* = 2 094	Black *N* = 1 222	Hispanic *N* = 1 089	Asian *N* = 666
Much higher than ave (> *95th*)	> 188	> 189	> 189	> 183	> 181
Higher than ave (*75th–95th*)	181–188	183–189	182–189	177–183	176–181
Average (*25th–75th percentile*)	171–181	173–182	172–181	167–176	167–175
Lower than ave (*5th–25th*)	163–171	166–172	165–171	160–166	159–166
Much lower than ave (< *5th*)	< 163	< 166	< 165	< 160	< 159
Mean ± *SEM*	**175.7 ± 0.2**	**177.1 ± 0.3**	**176.4 ± 0.3**	**171.3 ± 0.3**	**170.3 ± 0.4**
Women Category (*Percentile*)	**Total** *N* = 5 547	**White** *N* = 2 199	**Black** *N* = 1 302	**Hispanic** *N* = 1 186	**Asian** *N* = 708
Much higher than ave (> *95th*)	> 174	> 174	> 174	> 169	> 167
Higher than ave (*75th–95th*)	167–174	168–174	168–174	163–169	162–167
Average (*25th–75th percentile*)	158–166	159–167	160–167	154–162	153–161
Lower than ave (*5th–25th*)	150–157	152–158	151–159	147–153	146–153
Much lower than ave (< *5th*)	< 150	< 152	< 151	< 147	< 146
Mean ± *SEM*	**161.8 ± 0.2**	**162.9 ± 0.2**	**163.0 ± 0.3**	**157.5 ± 0.2**	**157.0 ± 0.4**

Source: Fryar, Gu, Ogden, & Flegal (2016).[5]

Table 3.5 Category for Weight (kg) by Gender and Race (United States, 2011–2014)

Men Category (*Percentile*)	Total *N* = 5 236	White *N* = 2 099	Black *N* = 1 222	Hispanic *N* = 1 089	Asian *N* = 665
Much higher than ave (> *95th*)	> 124.9	> 124.8	> 133.9	> 120.2	> 97.9
Higher than ave (*75th–95th*)	99.3–124.9	100.5–124.8	103.1–133.9	95.0–120.2	79.9–97.9
Average (*25th–75th percentile*)	75.0–99.2	76.8–100.4	73.3–103.1	73.4–94.9	64.6–79.8
Lower than ave (*5th–25th*)	62.0–74.9	63.9–76.7	59.0–73.2	60.9–73.3	53.7–64.5
Much lower than ave (< *5th*)	< 62.0	< 63.9	< 59.0	< 60.9	< 53.7
Mean ± *SEM*	**88.8 ± 0.4**	**90.2 ± 0.6**	**90.4 ± 0.7**	**86.1 ± 0.9**	**73.0 ± 0.5**
Women Category (*Percentile*)	**Total** *N* = 5 425	**White** *N* = 2 157	**Black** *N* = 1 264	**Hispanic** *N* = 1 166	**Asian** *N* = 691
Much higher than ave (> *95th*)	> 116.5	> 116.2	> 128.7	> 109.3	> 80.8
Higher than ave (*75th–95th*)	86.8–116.5	86.4–116.2	98.9–128.7	84.5–109.3	65.2–80.8
Average (*25th–75th percentile*)	61.8–86.7	62.4–86.3	70.0–98.8	61.6–84.4	51.4–65.1
Lower than ave (*5th–25th*)	50.1–61.7	50.9–62.3	54.9–69.9	51.3–61.5	45.3–51.3
Much lower than ave (< *5th*)	< 50.1	< 50.9	< 54.9	< 51.3	< 45.3
Mean ± *SEM*	**76.4 ± 0.4**	**76.4 ± 0.5**	**86.3 ± 0.7**	**74.7 ± 0.6**	**59.6 ± 0.6**

Source: Fryar, Gu, Ogden, & Flegal (2016).[5]

exceed the average heights for Hispanic men (171.3 cm) and for Asian men (170.3 cm) by more than 5 cm. The same trend holds true in women, where the average heights for white women (162.9 cm) and for black women (163.0 cm) both exceed the average heights for Hispanic women (157.5 cm) and for Asian women (157.0) by more than 5 cm. The racial/ethnic trends in body weight are similar to height in men but not as much in women. The average weights for white men (90.2 kg) and for black men (90.4 kg) are similar and both exceed the average weight for Hispanic men (86.1 kg) by 4 kg and far exceed the average weight for Asian men (73.0 kg) by 17 kg. The average weight for black women (86.3 kg) exceeds that for white women (76.4 kg) and for Hispanic women (74.7 kg) by nearly 10 kg, and far exceeds the average weight for Asian women (59.6 kg) by 16 kg.[5]

Body Weight Ranges Derived from Height

What constitutes an ideal, appropriate, or normal body weight for the average adult is a subject for debate. Numerous tables in books and magazines and on the Internet provide some form of "desirable" weight based on gender, age, height, race/ethnicity, frame size, or any combination of these variables. For the purpose of this laboratory manual, comparative body weight ranges are derived from height based on body mass index (BMI). BMI (discussed further in Chapter 23) is a measure of a person's degree of obesity and is calculated as the ratio of body weight divided by height squared. Values of BMI are used to classify a person's body weight into one of the following categories: "underweight" (BMI $<$ 18.5), "normal weight" (BMI = 18.5–24.9), "overweight" (BMI = 25.0–29.9), "class I (mild) obesity" (BMI = 30.0–34.9), "class II (moderate) obesity" (BMI = 35.0–39.9), or "class III (extreme) obesity" (BMI $>$ 40.0).[11] Table 3.6, using the "normal" BMI (18.5–24.9), demonstrates a "normal" body weight range for adults based on height, but regardless of gender or age.

Changes in Average Height and Body Weight over Years

The Department of Health and Human Services regularly administers surveys to collect anthropometric reference data for children and adults in the United States. One long-running survey is known as the National Health and Nutrition Examination Survey (NHANES). A comparison of data from four cycles of the survey (1988–1994,[9] 1999–2002,[8] 2003–2006,[10] and 2011–2014[5]) is presented in Table 3.7. The comparison reveals a minimal increase in height regardless of ethnicity in men of 0.1 cm and no change in the height of women over the 20 years (1994–2014). It appears that Hispanic men and women increased more than any other group over that time with increases in mean height of 1.6 cm (0.9 %) and 0.8 cm (0.5 %), respectively. The change in body weight over time is more dramatic with the average body weight in all U.S. men increasing 6.7 kg (7.5 %) from 82.1 kg to 88.8 kg. The average body weight for all U.S. women increased 7.2 kg (9.4 %) from 69.2 kg to 76.4 kg. The average body weight of Hispanic (including Mexican American) men increased more than any other group increasing 8.8 kg (10.0 %) from a mean weight of 77.5 kg in 1994 to 86.1 kg in 2014. The average body weight of black (African American) women increased more than any other group increasing 9.8 kg (11.4 %) from a mean weight of 76.5 kg in 1994 to 86.3 kg in 2014, which outweighs Hispanic and Asian men living in the United States.[5,8,9,10]

Table 3.6 Body Weights Classified as "Normal" Derived from Height Using Body Mass Index (BMI)

Height		"Normal Body Weight" (BMI = 18.5–24.9)	
cm	in.	kg	lb
142	56.00	37.4–50.4	83–111
144	56.75	38.4–51.7	85–114
146	57.50	39.5–53.1	87–117
148	58.25	40.5–54.5	89–120
150	59.00	41.5–55.9	92–123
152	59.75	42.6–57.4	94–126
154	60.75	44.0–59.3	97–131
156	61.50	45.1–60.8	100–134
158	62.25	46.3–62.3	102–137
160	63.00	47.4–63.8	104–141
162	63.75	48.5–65.3	107–144
164	64.50	49.7–66.8	109–147
166	65.25	50.8–68.4	112–151
168	66.25	52.4–70.5	115–155
170	67.00	53.6–72.1	118–159
172	67.75	54.8–73.7	121–163
174	68.50	56.0–75.4	123–166
176	69.25	57.2–77.0	126–170
178	70.00	58.5–78.7	129–174
180	70.75	59.7–80.4	132–177
182	71.75	61.4–82.7	135–182
184	72.50	62.7–84.4	138–186
186	73.25	64.0–86.2	141–190
188	74.00	65.4–88.0	144–194
190	74.75	66.7–89.8	147–198
192	75.50	68.0–91.6	150–202
194	76.50	69.8–94.0	154–207
196	77.25	71.2–95.9	157–211
198	78.00	72.6–97.7	160–215

Note: "Normal" body weight is derived from a "normal" body mass index (BMI), which is 18.5–24.9. *Source:* National Heart, Lung, and Blood Institute (1998).[11]

Effect of Time of Day

The time of day appears to have a small but significant effect on height. Based on measurements taken on one young male (age 13 y) in the morning (within 30 minutes of rising) and repeated before bed on 300 separate days, a 0.98 $\pm$ 0.2 cm decrease in height occurred during the course of the day.[7] Another study of 50 older women looked at diurnal changes in height. The results revealed a significant height decrease ($>$ 6 mm) over the course of the day. Interestingly, it was

Table 3.7 Change in Mean Height and Weight by Survey Year, Gender, and Race

Group	Height				Height change from:		Weight				Weight change from:	
	1994[a]	2002[b]	2006[c]	2014[d]	94 to 14	06 to 14	1994[a]	2002[b]	2006[c]	2014[d]	94 to 14	06 to 14
	cm	cm	cm	cm	cm (%)	cm (%)	kg	kg	kg	kg	kg (%)	kg (%)
Men (Total)	175.6	176.0	176.3	175.7	0.1 (0.1 %)	–0.6 (–0.3 %)	82.1	86.3	88.3	88.8	6.7 (7.5 %)	0.5 (0.6 %)
White	176.5	177.2	177.5	177.1	0.6 (0.3 %)	–0.4 (–0.2 %)	83.2	87.9	89.6	90.2	7.0 (7.8 %)	0.6 (0.7 %)
Black	176.1	176.9	177.2	176.4	0.3 (0.2 %)	–0.8 (–0.5 %)	82.5	86.2	90.6	90.4	7.9 (8.7 %)	–0.2 (–0.2 %)
Hispanic	169.7	169.6	170.3	171.3	1.6 (0.9 %)	1.0 (0.6 %)	77.5	80.0	81.9	86.1	8.6 (10.0 %)	4.2 (4.9 %)
Asian	-	-	-	170.3	-	-	-	-	-	73.0		
Women (Total)	161.8	162.1	162.2	161.8	0.0 (0.0 %)	–0.4 (–0.2 %)	69.2	74.1	74.7	76.4	7.2 (9.4 %)	1.7 (2.2 %)
White	162.3	162.9	163.0	162.9	0.6 (0.4 %)	–0.1 (–0.1 %)	68.5	73.6	74.3	76.4	7.9 (10.3 %)	2.1 (2.7 %)
Black	163.0	163.0	162.7	163.0	0.0 (0.0 %)	0.3 (0.2 %)	76.5	82.9	83.8	86.3	9.8 (11.4 %)	2.5 (2.9 %)
Hispanic	156.7	157.4	157.8	157.5	0.8 (0.5 %)	–0.3 (–0.2 %)	68.9	71.2	73.6	74.7	5.8 (7.8 %)	1.1 (1.5 %)
Asian	-	-	-	157.0	-	-	-	-	-	59.6		

Source: [a] McDowell, Fryar, & Ogden (2009)[9]; [b] McDowell, Fryar, Hirsch, & Ogden (2005)[8]; [c] McDowell, Fryar, Ogden, & Flegal (2008)[10]; [d] Fryar, Gu, Ogden, & Flegal (2016).[5]

BOX 3.3 Chapter Preview/Review

What is meant by the term *stature*?
What are some of the purposes of measuring height?
What is a stadiometer?
How good is the test-retest reliability of height and weight measurements?
How well do people "self-report" height and weight?
When is it preferred to use nude body weight and "exercise-clothed" body weight?
During which decade of life is height and weight observed to peak in men and women?
How does race/ethnicity influence height and weight?
How does the time of day potentially affect height and body weight?

also observed that height increased (> 5 mm) after lying supine for an average period of 49 minutes.[4] The observation of diurnal changes in height has practical consideration for the study of osteoporosis in particular. Because osteoporotic vertebral fractures result in loss of height, longitudinal measure of height in older adults may be useful in detecting the onset of osteoporosis and monitoring its progress. But these measurements should be taken at the same time of day to minimize any potential error due to normal daily variation in height.

It is also common to observe daily changes in body weight over the course of the day. Body weight can be influenced rapidly by food intake, fluid intake, salt intake, exercise, fluid loss, illness (vomiting and diarrhea), hormonal status (more so in women) and other factors. These daily changes in weight for the most part go unnoticed. However, some people, when trying to lose weight, choose to step on the scale frequently throughout the day. This can lead to confusing and frustrating results when they see 1–2 kg fluctuations in weight throughout the day. It might be recommended in this case that they weigh themselves only once per day, at the same time of day (typically in the morning), after going to the bathroom, and before eating or drinking anything. This is the best way to get a "true" body weight, along with the use of an accurate scale.

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Form 3.1 Collection of Basic Data — Homework

Name: ____________________ Date: __________ Score: ________

Laboratory / Meterological Data

Room termperature	**23**	°C	____	K	____	°F
Barometric pressure	**755**	mm Hg	____	hPa	____	in. Hg
Relative humidity	**40**	%				

Male Participant Participant initials **AA** Race/ethnicity* (W, B, H, A, O) **W**

Age (y): **22** Height (in.): **70.25** *(closest 0.25 in.)* Height (cm): ________ *(closest 1 cm)*

Weight (lb): **165.75** *(closest 0.25 lb)* Weight (kg): ________ *(closest 0.1 kg)*

Height category by race/ethnicity *(Table 3.4)* ____________________

Weight category by race/ethnicity *(Table 3.5)* ____________________

"Normal" body weight *(Table 3.6)* ______ – ______ kg ______ – ______ lb Within range: ________

Female Participant Participant initials **BB** Race/ethnicity* (W, B, H, A, O) **B**

Age (y): **21** Height (in.): **65.00** *(closest 0.25 in.)* Height (cm): ________ *(closest 1 cm)*

Weight (lb): **158.25** *(closest 0.25 lb)* Weight (kg): ________ *(closest 0.1 kg)*

Height category by race/ethnicity *(Table 3.4)* ____________________

Weight category by race/ethnicity *(Table 3.5)* ____________________

"Normal" body weight *(Table 3.6)* ______ – ______ kg ______ – ______ lb Within range: ________

* Race / Ethnicity: White (W); Black (B); Hispanic (H); Asian (A); Other / none (O)

Optional

Height *(closest 0.1 cm)*:	Early in day	**178.1**	Late in day	**176.5**	Difference	____	cm
Weight *(closest 0.1 kg)*:	Early in day	**78.5**	Late in day	**79.3**	Difference	____	kg
Nude weight *(closest 0.1 kg)*:	Body wt	**78.0**	Clothes wt	**0.4**	Nude wt	____	kg

Form 3.2 Collection of Basic Data **Lab Results**

Name: ______________________ Date: __________ Score: ________

Laboratory / Meterological Data

Room termperature ________ ˚C ________ K ________ ˚F

Barometric pressure ________ mm Hg ________ hPa ________ in. Hg

Relative humidity ________ %

Male Participant Participant initials _____ Race/ethnicity* (W, B, H, A, O) _____

Age (y): _____ Height (in.): ________ *(closest 0.25 in.)* Height (cm): ________ *(closest 1 cm)*

Weight (lb): ________ *(closest 0.25 lb)* Weight (kg): ________ *(closest 0.1 kg)*

Height category by race/ethnicity *(Table 3.4)* ____________________

Weight category by race/ethnicity *(Table 3.5)* ____________________

"Normal" body weight *(Table 3.6)* ______ – ______ kg ______ – ______ lb Within range: ________

Female Participant Participant initials _____ Race/ethnicity* (W, B, H, A, O) **B**

Age (y): _____ Height (in.): ________ *(closest 0.25 in.)* Height (cm): ________ *(closest 1 cm)*

Weight (lb): ________ *(closest 0.25 lb)* Weight (kg): ________ *(closest 0.1 kg)*

Height category by race/ethnicity *(Table 3.4)* ____________________

Weight category by race/ethnicity *(Table 3.5)* ____________________

"Normal" body weight *(Table 3.6)* ______ – ______ kg ______ – ______ lb Within range: ________

* Race / Ethnicity: White (W); Black (B); Hispanic (H); Asian (A); Other / none (O)

Optional Height *(closest 0.1 cm)*: Early in day ________ Late in day ________ Difference ________ cm

Weight *(closest 0.1 kg)*: Early in day ________ Late in day ________ Difference ________ kg

Nude weight *(closest 0.1 kg)*: Body wt ________ Clothes wt ________ Nude wt ________ kg

CHAPTER 4

Isotonic (Dynamic) Strength

Isotonic exercise is also referred to or defined as dynamic exercise. It is exercise that consists of muscle actions that are concentric or eccentric, depending on whether the muscles shorten or are lengthened. During isotonic or dynamic exercise, the speed of movement is variable throughout the movement, such as when lifting a barbell. Thus, the load being lifted changes speed, due to biomechanical, physiological, and anatomical factors of the lifter, but the absolute load itself (the mass of the load) does not change.[18]

Field tests of strength have existed since at least the time of the ancient Olympics, when contestants were required to lift a ball of iron in order to qualify for the games. In 1873, Dudley Sargent, a pioneer in early physical education, initiated strength testing at Harvard University. Currently, many strength trainees measure their strength in the weight room using free-weights and weight machines.

A popular free-weight exercise that is described as an isotonic or dynamic strength test in this chapter is the bench press. Depending on the controlled or standardized conditions, the free-weight test described here could be classified as a field or laboratory test.[11,37] This chapter includes a description of both direct and indirect (predicted; estimated) measures of dynamic strength for the muscle groups used in performing this free-weight exercise.

Rationale

One of the most operational (easily applied) definitions of dynamic strength states that it is expressed as a person's *one repetition maximum* (1 RM) for a specific movement, such as the bench press. This 1 RM is the maximum load or weight that a person can lift only one time. It can be directly measured from a maximal effort or it can be indirectly estimated from a submaximal effort.

Directly Measured 1 RM

A direct measure of strength is the maximal weight that a person can lift in the prescribed manner only one time. A brief preview of the traditional 1 RM test would show that it requires a person to exert maximally on a selected weight, chosen as close as possible to the person's expected 1 RM weight. If the person cannot lift it with correct form, then a lower weight is tried after a rest interval; if the person properly lifts the weight twice, then the participant stops. After a rest interval, a small additional weight is added, and the person tries again. This process is repeated until only one repetition is possible.[25] Obtaining the 1 RM value for the first time in a person may be inaccurate and time consuming because of the number of attempts at achieving one, and only one, repetition at a given weight[21] and a lack of standardizing the lifting position or procedures. Direct 1 RM measurements also may be injurious for some persons, especially children[16] and the elderly.[34] The American Academy of Pediatrics[1] and the National Strength and Conditioning Association[32] endorse this sentiment in not recommending 1 RM performances by children.

Indirectly Estimated 1 RM

If for some reason directly measuring 1 RM is not possible or desirable, the 1 RM may be indirectly estimated by knowing the number of submaximal repetitions to fatigue (RTF) for any given weight lifted. The 1 RM may be estimated from equations based upon either a linear relationship[6,22,32] or a curvilinear (exponential) relationship[25,35] between the number of RTF and the percent of 1 RM (% 1 RM). An example of both of these relationships is seen in Figure 4.1. The 1 RM can be estimated from measuring the number of RTF at intensities between 75 % and 95 % 1 RM,[14,17,19] and possibly extended to intensities as low as 60 % 1 RM.[14,29] Generally, however, it is believed that estimations of 1 RM using such equations are best when using a load that results in no more than 10 repetitions to fatigue (~ 75 % of 1 RM).[6,27]

One indirect 1 RM method is based on a *linear* relationship between % 1 RM and the number of submaximal repetitions to fatigue.[32] If 4 repetitions to fatigue are completed, this would be considered the number of repetitions or 4 RM (4 reps to fatigue), 5 RM (5 reps to fatigue), etc. In general, the % 1 RM load decreases by about 2.5 % for each increase in the number of repetitions to fatigue, keeping in mind the assumption of a linear relationship. Thus, the 1 RM load represents 100 % 1 RM that can be lifted only once, whereas an 80 % 1 RM load could be lifted about 8 times. The % 1 RM can be estimated for a set of submaximal repetitions by assuming the 2.5 % decrease per RM, which can then be used to estimate the 1 RM. Another indirect 1 RM method is based on a *curvilinear* (or *exponential*) relationship between % 1 RM and the number of submaximal repetitions to fatigue.[25] This method is very similar to the linear method except that the estimated % of 1 RM is mathematically based on the exponent of the

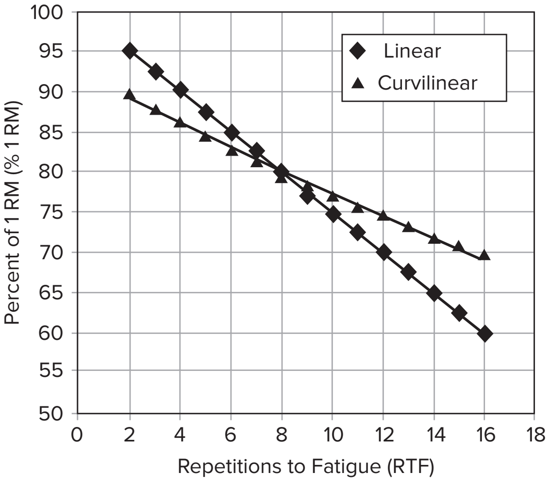

Figure 4.1 The linear and curvilinear (exponential) relationships between repetitions to fatigue (RTF) and percent of 1 repetition maximum (% 1 RM).

number of repetitions to fatigue. Because of this, the curvilinear method yields estimates of 1 RM that are slightly higher than the linear method when a low number of repetitions are completed (3–5 RM), but slightly lower estimates of 1 RM with higher numbers of repetitions to fatigue (10–12 RM), as seen in Figure 4.1.

Anatomical Rationale

Many major muscles in the upper body are involved in a bench press exercise. The primary muscles involved include those of the chest (pectoralis major), shoulders (anterior deltoid and coracobrachialis), and arms (triceps brachii). For this reason, the bench press was chosen to use in assessing 1 RM in this chapter.

Physiological Rationale

The biochemical pathway for maximal muscle actions—that is, strength—is the phosphagenic pathway. Even the longest of 1 RM movements is completed in less than 10 s; this includes the time spent holding the weight prior to the movement, raising the weight, holding it in the lifted position, and lowering the weight.[31] Thus, the actual time spent raising the weight is usually less than three seconds. Maximal exercise efforts of this duration are placed within the anaerobic fitness category.

Tests of Strength (1 RM), Work, and Power

Two tests of strength are described; one *directly measures* the most weight lifted one time (1 RM) and the other *indirectly estimates* this value through the use of multiple submaximal lifts to fatigue (typically 3–12 repetitions). Strength testing serves purposes related to both performance and health. Before embarking on strength training programs, it is meaningful to evaluate participants in order to prescribe their programs and monitor their progress. For example, a trainee's exercise prescription may include performance of two or three sets of maximal repetitions at 80 % of the 1 RM load. Persons, especially women, who habitually exert forcefully against resistance may protect themselves from losing bone density.[2,4] It seems plausible that stronger persons are more likely to provide the necessary forces to prevent the advent of porous bones, associated with osteoporosis.

Additionally, directions are included for the quantification of work and power. This goes beyond the purpose of simply measuring strength. Because of the distinct terminology and measurement in exercise physiology, the purpose of this exercise is to familiarize the student with common exercise terms and measurement associated with work and power. Thus, in addition to learning how to administer the strength tests, students also learn how to measure positive (concentric) work, negative (eccentric) work, total work, and mean power.

Methods

The Methods section of a research paper should enable the readers to replicate the researcher's study. This means that the equipment (instruments and materials), procedures, and calculations (analysis) are described in the Methods section. Box 4.1 provides a summary of the accuracy of 1 RM testing.

Equipment

Various instruments are available to measure muscle strength. Some of these are (a) free-weights (e.g., barbells), (b) dynamometers, (c) cable tensiometers, (d) load cells (electromechanical devices), and (e) isokinetic devices. The equipment for the isotonic strength and power tests includes the following: (1) weighing scale (e.g., platform scale or electronic scale); (2) bar; (3) assorted free-weights ranging from 1 kg ($\approx$ 2.5 lb; 10 N) to 10 kg ($\approx$ 25 lb; 100 N) each; (4) barbell collars (unless weights are welded onto the bar); (5) stopwatch capable of measuring to a tenth of a second; and (6) a metric tape or stick.

Weighing scales, used to measure the weight and force components, were discussed in Chapter 3. Most weight rooms have barbells and weights to measure the force component of work and power. A total weight of about 125 kg (275 lb) should accommodate most participants. One bench is needed for the strength exercise described here. Most exercise physiology laboratories have metric measurement tapes and stopwatches to measure the distance and time components of work and power, respectively. Students are encouraged to bring their own calculators and wristwatches (chronographs) to every laboratory session.

BOX 4.1 Accuracy of 1 RM Testing

Regardless of the accuracy of the equipment and the diligence of the examiner and participant, strength scores in participants will vary due to daily biological variability; this may cause strength scores in an individual to change by 2 % to 12 %.[43] When the 1 RM strength was determined for a two-arm curl performed two days apart on a custom-made weight machine, the test-retest correlation was .98. This correlation may not be as high, however, for two-arm curls performed with free-weights because of less standardization of body position and movement.[41] The test-retest variation of 1 RM and predicted 1 RM ranges from 5 % to 15 %.[3] Thus, if on one day a person's maximal lift is 50 kg, or is predicted to lift 50 kg, then on a subsequent day that person's 1 RM, or predicted 1 RM, may be any value between 47.5 kg and 52.5 kg if at the least variability, and 42.5 kg and 57.5 kg at the most variability. Test-retest reliability is likely to be higher if the average of a few trials is used rather than the highest score of a few trials.[7]

The traditional direct method of measuring dynamic strength is not without its inconsistencies, especially for inexperienced lifters. Because 1 RM strength trials may increase significantly from trial one to trial two, especially in older adults,[36] the second trial of another day should be used[3] as the baseline for strength-training intervention studies. It would be inappropriate to attribute all strength gains to the resistance training program on the basis of strength scores from trial one.

Although the National Football League (NFL) test of strength for prospective players is not exactly like the predictive ones described here, it is similar enough to provide some input as to the accuracy of such predictive 1 RM tests. The NFL prescribes an absolute weight of 225 lb (102 kg) to be bench pressed as many times as possible (repetitions maximal; RM). Their valid test (r = .96) predicted 1 RM strength in college football players, who required about seven repetitions to fatigue. The prediction appeared to be most accurate for those players who performed 10 RM or less.[7,24]

When predicting 1 RM from repetitions maximal, some inaccuracy may occur in assuming that there is a 2.5 % decrease in any given person's 1 RM mass for each single increase of repetitions maximal. For example, this would assume that 10 RM is approximately 80 % of 1 RM mass. However, one reviewer reported a range from 60 % to 90 % for persons performing 10 repetitions maximal.[30] The initial strength and resistance training experience of the participant can affect the prediction of 1 RM.[5] This inverse linear relationship also appears to vary with different muscle groups.[8] Indirect, submaximal tests of 1 RM appear to be accurate in exercises involving small muscle groups (e.g., bench press, arm curl) but often overestimate 1 RM in exercises involving large muscle groups (e.g., back squat, leg press).[39,42]

The measurement of power for the bench press, using a 90 % 1 RM method, revealed a test-retest correlation of .97.[3]

Safety is a concern for all fitness tests, especially those requiring intense or explosive movements and those leading to exhaustion. Box 4.2 provides a safety checklist for technicians and participants.

BOX 4.2 Safety Checklist for Lifting

1. Be alert for situations that might cause accidents, collisions, stumbles, and dropped weights such as other people, uneven floormats, overhangs, benches, and weights on the floor.
2. Perform a prior exercise regimen of stretching and warming up (light lifting).
3. Use the hooked-thumb (hook) grip, not a thumb less grip, to provide additional safety.
4. Check that any adjustable collars are tight.
5. Use spotters wisely:
   - If using one spotter, place the spotter behind the bench press participant.
   - If using two spotters, place the spotters at each end of the barbell.
   - Keep clear communication between spotter(s) and the participant throughout the effort.
   - "Ready"—participant calls "ready" and spotter(s) help remove bar from holder and place into starting position. "Done"—participant calls "done" on the last repetition and spotter(s) help return bar to the holder/rack.
6. Help protect the participant's and spotter's back by keeping weights close to the body when handling the weights while loading the bar and lifting the weights, avoiding any twisting while handling the bar, and activating the abdominal muscles while loading and lifting the weights.
7. Breathe properly and fully while lifting—exhale from the mouth during the concentric phase and inhale through the mouth during the eccentric phase.

Executing the Bench Press Exercise

The accuracy of free-weight strength testing is enhanced if the execution of the lifts is standardized. The prescribed positions of the bench press are illustrated in Figure 4.2. These movements should be practiced a few times with only the bar. The technician ensures that the participant executes properly.

1. The participant lies supine on a wide bench with the knees bent and the soles of the feet on the floor. Alternately, the feet may be on the bench with novice lifters to prevent arching the back and risking injury.[10,23]
2. Two technicians, or spotters, at each side of the participant, or one spotter behind the participant, place the barbell in the participant's pronated hands (thumbs medial) spaced slightly wider (up to 20 cm) then shoulder width apart and at chest level.[42]
3. The participant raises the weight to a straightened-arms position directly above the chest.
4. The participant returns the barbell to the preparatory position (in contact with the chest).
5. The participant stops at this position for about 1 s before initiating subsequent repetitions.

Preparation for 1 RM, Work, and Mean Power

As with all of the tests performed in this manual, the first step is to record the basic data. Thus, the name, date, age, gender, height, and weight are recorded on Form 4.2. An additional

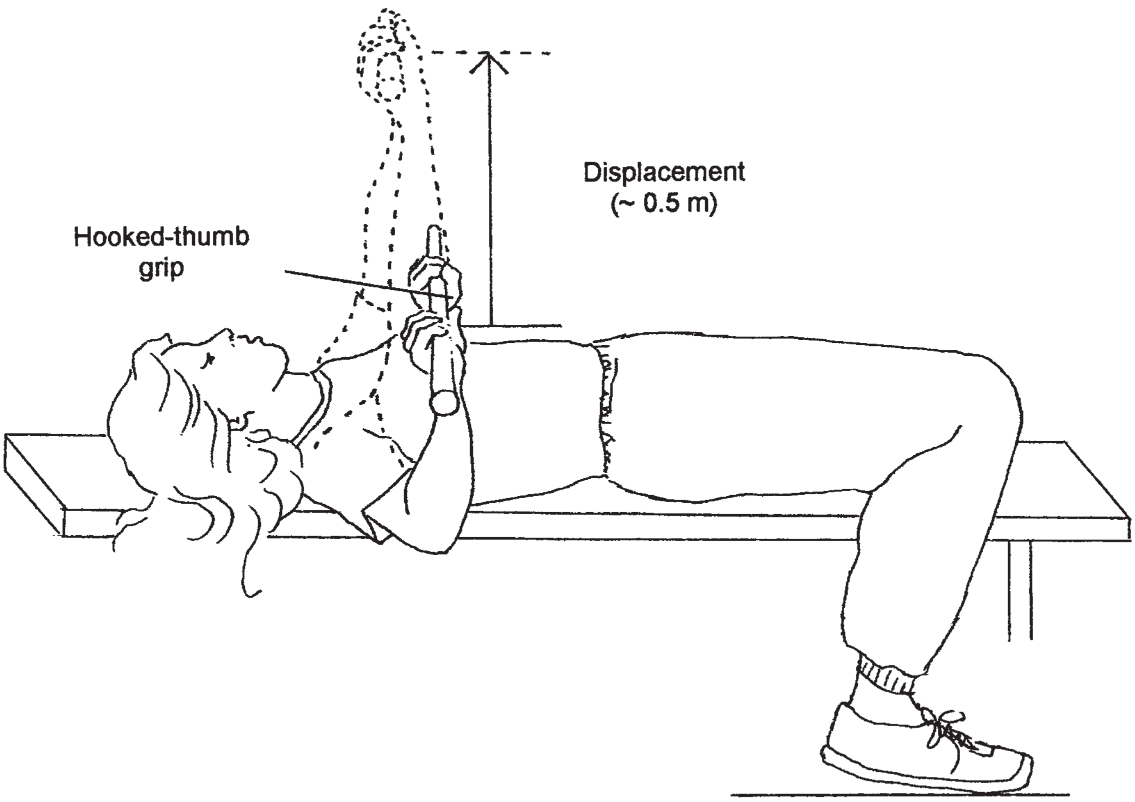

Figure 4.2 The beginning and end positions for the bench press. The arrow denotes the vertical displacement measurement needed for calculating work and power.

factor, specific for free-weight testing, might be the recording of the participant's experience in lifting free-weights. The body weight should be as close to the nude weight as possible and measured according to the procedures described in Chapter 3.

Another universal step is to calibrate the test equipment. The calibration of the platform scale was described in Box 3.2 of Chapter 3. It is not unusual for the poundage of commercial weights to be labeled inaccurately. For example, in one instance a sand-filled weight that was marked as 8.8 lb (4.0 kg) really weighed 10.4 lb (4.7 kg). Hence, the weights, barbells, and collars that are to be used for testing should be verified on an accurate scale prior to testing. The actual kilograms or pounds should be marked on the barbells or weights.

In some instances, weight (or mass) is considered equal to the force lifting the weight, such as when lifting a barbell against gravitational forces. The weight (free-weights), which in this case is the force, should be measured on a metric scale to the closest tenth kilogram or be converted to metrics after being weighed on a nonmetric scale.

Before the subject performs the maximal repetitions for a given weight, displacement (d) measurements must be made in order to calculate the work ($w = F * d$) accomplished. The displacement[a] is measured to the closest centimeter with a metric tape. It is made with the participant using an unloaded bar at two points: the preparatory and end points of the movement. The criteria for measuring these lengths are illustrated in Figure 4.2.

After making the vertical displacement measures, the participant should be given 5–10 min of prior exercise, consisting of stretching and warming-up (weight lifting) exercises. These exercises should incorporate the muscles to be used in the strength test. Thus, the stretching exercises should stretch the upper body muscles and tendons. One warm-up set of about eight repetitions should mimic the execution of the lift, but with weights that are about 40 %[38] to 60 %[18] of an estimated one repetition maximal. This can be followed by another set of three repetitions between 50 % and 70 % of estimated 1 RM or three to five reps at 60 % to 80 %. These preliminary estimates are rather exploratory for first-time participants (novices).

Direct Measurement of Bench Press 1 RM

The direct method is the traditional trial-and-retrial method. The results may be compared with the results of the indirect method. Hence, the comparison can serve as a validation of the indirect method.

[a]The term *displacement* represents the straight-line length of the concentric phase of the exercise. The term *distance* includes the curved-line length (the arc) of concentric and eccentric phases of the exercise.

The procedures outlined here[20,33,45] combine those described by others. The procedural steps for the traditional direct measurement of 1 RM follow.

Technician Preparation

1. Calibrate the platform scale or electronic scale. (Refer to Box 3.2 in Chapter 3.)
2. Weigh and mark the barbells and assorted free-weights to the closest 0.1 kg.
3. Record basic data onto Form 4.2. Record height to the closest 1 cm and body weight (as close to nude weight as possible) to closest 0.1 kg.
4. Explain and demonstrate the proper execution of the bench press using only the bar. Provide as much detail as needed based on the previous weight lifting experience of the participant.
5. For novice lifters, load the bar with weight based on the body weight of the participant. For men, load the bar with about 50 % of body weight. For women, load the bar with about 30 % of body weight. For experienced lifters, load the bar with weight that approximates 50 % 1 RM.

Participant Preparation

1. Practice the bench press exercise with just the bar until performance is satisfactory to the technician.
2. Complete a warm-up set of 8–10 reps at the previously prescribed weight (50 % of body weight for novice men, 35 % of body weight for novice women, or 50 % 1 RM for more experienced lifters). The goal is a warm-up set of 8–10 reps at 40–60 % 1 RM. Rest for 1 minute with active recovery and stretching if desired.
3. Complete another warm-up set of 3–5 reps at a weight 5–10 kg (10–20 lb) higher than the first. The goal is another warm-up set of 3–5 reps at 60–80 % 1 RM. Rest for 1 minute with active recovery and stretching if desired.

Test Procedures

1. The technician loads the bar with an estimated near maximal weight (90–95 % 1 RM) by adding 5–10 kg (10–20 lb) to the weight used for the second warm-up set. This weight is recorded as Trial 1 on Form 4.2.
2. The participant completes 2–3 reps at this weight (estimated to be 90–95 % 1 RM). The participant rests 1–2 min (or longer) with active recovery and stretching if desired.
3. The technician loads the bar with an additional 5–10 kg (10–20 lb) to estimate the 1 RM. The participant attempts one single rep at this weight.
   a. *If successful,* the technician records this weight as Trial 2 on Form 4.2. The participant rests 1–2 min (or more), then repeats Step 3 until the 1 RM is reached and recorded on Form 4.2.
   b. *If unsuccessful,* the technician unloads 5–10 kg (10–20 lb) from the bar. The participant rests 1–2 min (or more), then attempts another single rep at this reduced weight.
      i. *If successful,* the participant rests 1–2 min (or more), then repeats Step 3 until the 1 RM is reached.
      ii. *If unsuccessful,* the participant is done and Trial 1 is considered the 1 RM.
4. Ideally, the participant's 1 RM is reached within five trials. If more attempts are needed, the participant should be retested on another day.[45]

Indirect Estimate of Bench Press 1 RM

The prediction of 1 RM may be made based on either a linear relationship or a curvilinear relationship between % 1 RM and # RM. The focus of the following is based on the more popular, but not necessarily more accurate, linear relationship. The ultimate step in predicting 1 RM is to determine the participant's maximal number of repetitions for a given weight (force). Repetitions maximal (# RM) is defined as the number of repetitions, without a rest interval, performed until no other properly executed repetition can be completed. In order to comply with the linearity rationale, it is best if the number of maximal repetitions does not exceed 20. If it is apparent that the participant is about to exceed 20 repetitions, stop the participant and wait for 5 min to 10 min before repeating the exercise at a heavier weight.

Technician Preparation

1. The technician completes Steps 1–5 as in the section "Direct Measurement of Bench Press 1 RM."

Participant Preparation

1. The participant completes Steps 1–2 as in the section "Direct Measurement of Bench Press 1 RM."

Test Procedures

1. The technician adds 5–10 kg (10–20 lb) to the bar over that weight used for the warm-up set. This weight is recorded as Trial 1 on Form 4.2.
2. The participant lifts the weight as prescribed for the movement as many times as possible at a comfortable pace, but without a rest interval. Ideally, the goal of the test is to lift the weight about 3–12 times to fatigue (3–12 RM).
   a. If the participant fatigues in 3–12 reps, that is acceptable and the test is complete. The technician records the number of repetitions beside the weight lifted for Trial 1 on Form 4.2.
   b. If the weight can be lifted less than 3 times or more than 12 times, the test should be repeated after a

Table 4.1 **Estimated Bench Press 1 RM from Number of Submaximal Repetitions (from 2 RM to 12 RM) at Repetition Weight (kg or lb) Based on a Generalized Linear Prediction Model**

Repetition Weight	2 RM 95.0 %	3 RM 92.5 %	4 RM 90.0 %	5 RM 87.5 %	6 RM 85.0 %	7 RM 82.5 %	8 RM 80.0 %	9 RM 77.5 %	10 RM 75.0 %	11 RM 72.5 %	12 RM 70.0 %
30	32	32	33	34	35	36	38	39	40	41	43
35	37	38	39	40	41	42	44	45	47	48	50
40	42	43	44	46	47	48	50	52	53	55	57
45	47	49	50	51	53	55	56	58	60	62	64
50	53	54	56	57	59	61	62	65	67	69	71
60	63	65	67	69	71	73	75	77	80	83	86
70	74	76	78	80	82	85	87	90	93	97	100
80	84	86	89	91	94	97	100	103	107	110	114
90	95	97	100	103	106	109	113	116	120	124	129
100	105	108	111	114	118	121	125	129	133	138	143
110	116	119	122	126	129	133	138	142	147	152	157
120	126	130	133	137	141	145	150	155	160	166	171
130	137	141	144	149	153	158	163	168	173	179	186
140	147	151	156	160	165	170	175	181	187	193	200
150	158	162	167	171	176	182	188	194	200	207	214
160	168	173	178	183	188	194	200	206	213	221	229
170	179	184	189	194	200	206	213	219	227	234	243
180	189	195	200	206	212	218	225	232	240	248	257
190	200	205	211	217	224	230	238	245	253	262	271
200	211	216	222	229	235	242	250	258	267	276	286

Source: Data used to estimate percentages of 1 RM from National Strength and Conditioning Association (2000).[32] % 1 RM = 100 − (# RM * 2.5).

Note: Table can be used to estimate 1 RM in either kilograms (kg) or pounds (lb).

5–10 min rest. The technician increases or decreases the weight on the bar by 5–10 kg (10–20 lb) and the participant repeats the test until fatigue is reached in 3–12 reps.

3. The technician estimates the 1 RM of the participant using the number of repetitions to fatigue (# RM) and the amount of weight lifted (kg or lb).
   a. The estimation of 1 RM can be made using the mathematical method described previously based on the *linear relationship*[32] between % 1 RM and the number of reps to fatigue (# RM). The % 1 RM is estimated for a set of submaximal repetitions (Eq. 4.1a). The 1 RM is then estimated by factoring in the weight lifted (Eq. 4.1b). The 1 RM may also be estimated based on the data presented in Table 4.1.

$$\%\,1\,\text{RM} = 100 - (\#\text{Reps} * 2.5) \qquad \text{Eq. 4.1a}$$

$$1\,\text{RM} = \text{Weight lifted} \;/\; (\%\,1\,\text{RM} / 100) \qquad \text{Eq. 4.1b}$$

For example, if a person completes 10 repetitions to fatigue of a particular weight, the % of 1 RM is estimated to be 75 % (Eq. 4.2a). If those 10 repetitions were completed with a load of 60 kg, then the 1 RM is estimated to be 80 kg (Eq. 4.2b). This same estimated 1 RM of 80 kg can be found in Table 4.1.

$$\%\,1\,\text{RM} = 100 - (\mathbf{10} * 25) = 75\,\% \qquad \text{Eq. 4.2a}$$

$$1\,\text{RM} = \mathbf{60}\,\text{kg} \;/\; (\mathbf{75} / 100) = \mathbf{80}\,\text{kg} \qquad \text{Eq. 4.2b}$$

   b. The 1 RM may alternately be estimated based on a *curvilinear* (*exponential*) *relationship*[25] between % 1 RM and the number of reps to fatigue and the weight lifted, as shown in Equations 4.3a and 4.3b. The symbol **e** in Eq. 4.3a represents the exponential function which is written e^x or often as exp(x) to avoid the use of the superscript. The calculation can be made on a scientific calculator using the e^x key or can be done in Excel® using the EXP function.

$$\%\,1\,\text{RM} = 52.5 + 41.9\,e^{-0.055\,*\,\text{Reps}} \qquad \text{Eq. 4.3a}$$

$$1\,\text{RM} = \text{Weight lifted} \;/\; (\%\,1\,\text{RM} \;/\; 100) \qquad \text{Eq. 4.3b}$$

For example, using the same data as above, where the participant completed 10 repetitions of a 60 kg load, the estimated % 1 RM is slightly higher at 76.7 % (Eq. 4.4a), yielding a slightly lower estimated 1 RM of 78 kg (Eq. 4.4a). This same estimated 1 RM of 78 kg can be found in Table 4.2.

$$\%\,\text{RM} = 52.2 + 41.9\,e^{-0.055\,*\,10} = \mathbf{76.7}\,\% \qquad \text{Eq. 4.4a}$$

$$1\,\text{RM} = \mathbf{60}\,\text{kg} / (\mathbf{76.7}\,\% / 100) = \mathbf{78}\,\text{kg} \qquad \text{Eq. 4.4b}$$

Evaluation of Bench Press Measurements

1. The technician compares the directly measured 1 RM with the indirectly estimated 1 RMs and completes the related items on Form 4.2.
2. The technician selects a category from Table 4.3 to evaluate the absolute 1 RM bench press strength,

Table 4.2 Estimated Bench Press 1 RM from Number of Submaximal Repetitions (from 3 RM to 12 RM) at Repetition Weight (kg or lb) Based on a Curvilinear (Exponential) Prediction Model

Repetition Weight	2 RM 90.0 %	3 RM 88.0 %	4 RM 86.1 %	5 RM 84.3 %	6 RM 82.6 %	7 RM 81.0 %	8 RM 79.5 %	9 RM 78.0 %	10 RM 76.7 %	11 RM 75.4 %	12 RM 74.2 %
30	33	34	35	36	36	37	38	38	39	40	40
35	39	40	41	42	42	43	44	45	46	46	47
40	44	45	46	47	48	49	50	51	52	53	54
45	50	51	52	53	54	56	57	58	59	60	61
50	56	57	58	59	61	62	63	64	65	66	67
60	67	68	70	71	73	74	75	77	78	80	81
70	78	80	81	83	85	86	88	90	91	93	94
80	89	91	93	95	97	99	101	103	104	106	108
90	100	102	105	107	109	111	113	115	117	119	121
100	111	114	116	119	121	123	126	128	130	133	135
110	122	125	128	130	133	136	138	141	143	146	148
120	133	136	139	142	145	148	151	154	156	159	162
130	144	148	151	154	157	160	164	167	169	172	175
140	156	159	163	166	169	173	176	179	183	186	189
150	167	170	174	178	182	185	189	192	196	199	202
160	178	182	186	190	194	198	201	205	209	212	216
170	189	193	197	202	206	210	214	218	222	225	229
180	200	205	209	214	218	222	226	231	235	239	243
190	211	216	221	225	230	235	239	244	248	252	256
200	222	227	232	237	242	247	252	256	261	265	270

Source: Data used to estimate percentages of 1 RM from Mayhew, Ball, Arnold, & Bowen (1992).[25] $\%\ 1\ RM = 52.2 + 41.9\ e^{-0.055 * Reps}$

Note: Table can be used to estimate 1 RM in either kilograms (kg) or pounds (lb).

Table 4.3 Category for 1 RM Bench Press Strength (kg) in Untrained Men and Women by Age Group

	Men			Women		
	18–29 y	**30–50 y**	**> 50 y**	**18–29 y**	**30–50 y**	**> 50 y**
Category (*Percentile*)	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**	**(kg)**
Well above ave (> *95th %ile*)	> 92.1	> 83.0	> 73.0	> 47.6	> 43.1	> 38.1
Above ave (*75th–95th %ile*)	76.9–92.1	69.4–83.0	61.0–73.0	42.2–47.6	38.3–43.1	33.8–38.1
Average (*25th–74th %ile*)	55.6–76.8	49.4–69.3	43.3–60.9	34.9–42.1	31.5–38.2	27.9–33.7
Below ave (*5th–24th %ile*)	40.4–55.5	35.8–49.3	31.3–43.2	29.5–34.8	26.8–31.4	23.6–27.8
Well below ave (< *5th %ile*)	< 40.4	< 35.8	< 31.3	< 29.5	< 26.8	< 23.6
Mean	**66.2**	**59.4**	**52.2**	**38.6**	**34.9**	**30.8**

Source: Data from Hockey (1989).[13]

selects a category from Table 4.4 to evaluate the relative 1 RM strength, and completes the related items on Form 4.2.

Estimation of Work and Mean Power

Timing the duration of the free-weight lift is necessary when calculating power because power is the rate of doing work. The timer should start the stopwatch at the participant's first movement of the bench press. The timer stops the watch when the participant returns the weight after the last complete or partial repetition. The timer records the time to the closest 0.1 s. The participant should execute the repetitions at a comfortable pace because the purpose of the power measurement is not to rank and compare the quality of the participant's mean power. If the latter were the goal, the participant would need to execute the maximal repetitions as fast as possible. No norms for this test could be found in the literature. The primary purpose of the mean power "test" is to become familiar with the concept of power and its calculation.[18]

The measurement of work and power can be completed in conjunction with the Indirect Estimate of 1 RM or independently. If it is to be completed in conjunction with this other test, the following preparation should be done prior to the Indirect Estimate of 1 RM.

Technician Preparation

1. The technician completes Steps 1–5 as in the section "Direct Measurement of Bench Press 1 RM."

2. Measure and record on Form 4.2 the vertical displacement of one concentric action of the participant's bench press (as indicated on Figure 4.2). This measurement allows for the calculation of work.
3. Have a stopwatch ready to measure the time elapsed during the complete exercise.

Participant Preparation

1. The participant completes Steps 1–2 as in the section "Direct Measurement of Bench Press 1 RM."

Test Procedures

1. The technician starts the stopwatch at the participant's first movement.
2. The participant lifts the weight as prescribed for the movement as many times as possible at a comfortable pace, but without a rest interval. Ideally, the goal of the test is to lift the weight about 6–10 times to fatigue (6–10 RM), but up to a maximum of 20 repetitions is allowed.
3. The technician counts and records on Form 4.2 the number of repetitions completed, including the fraction of a possible partial repetition on the last attempt. The weight lifted (kg) is converted into the force exerted (N), and recorded.
4. The technician stops the stopwatch at the end of the last attempt of a repetition and records the time to the closest 0.1 s onto Form 4.2.
5. If the participant exceeds 20 repetitions, the test should be repeated with a higher weight following a 5–10 min rest.
6. The technician completes the calculation of work and power as described below and completes the remaining items on Form 4.2.

Calculating Work and Power

Equation 4.5a is used to calculate the **positive work** (+w) from the weight lifted, expressed as force (F), the displacement (d) of a single concentric action, and the number of repetitions (# Reps). The latter will consist of more than one repetition (preferably 6 or more) and will include a somewhat subjective estimate of the fractional displacement of the final incomplete attempted repetition. For example, if the participant properly executes 9 complete repetitions of 50 kg (490 N) over 0.5 m, but attempts a 10th lift that only goes half the proper distance, then it is recorded as 9.5 reps and positive work is calculated as in Equation 4.5b. The result of the calculation ends up being in newton meters (N·m), which may also be expressed as joules (J), since 1 J is equal to 1 N·m.

$$+\,w(J) = \text{Force}(N) * \text{Displacement}(m / \text{Rep}) * \#\ \text{Reps} \quad \text{Eq. 4.5a}$$

$$+\,w(J) = \mathbf{490}\,N * \mathbf{0.5}\,m / \text{Rep} * \mathbf{9.5}\,\text{Reps} = \mathbf{2328}\,N{\cdot}m = \mathbf{2328}\,J \quad \text{Eq. 4.5b}$$

Positive work, however, accounts only for the concentric muscle action lifting the weight vertically against gravity. To measure the total work of these dynamic exercises, the eccentric muscle action must be considered and the **negative work** (–w) calculated (Eq. 4.6a). Although the estimate of negative work is variable, for the purpose of expressing the total work accomplished during a bench press exercise, negative work is assumed here to be 1/3 the positive work, based on the relationship of the metabolic cost between concentric and eccentric work.[2] Thus, using the data from the example above, the negative work (–w) can be calculated as in Equation 4.6b and the total work accomplished during the exercise as in Equations 4.6c and 4.6d. Total work can also be calculated "collectively" in one step, as seen in Equations 4.6e and 4.6f.

$$-w(J) = \text{Positive work}(J) * 0.33 \quad \text{Eq. 4.6a}$$

$$-w(J) = \mathbf{2328}\,J * 0.33 = \mathbf{768}\,J \quad \text{Eq. 4.6b}$$

$$\text{Total work}(J) = +\,w(J) + -w(J) \quad \text{Eq. 4.6c}$$

$$\text{Total work}(J) = \mathbf{2328}\,J + \mathbf{768}\,J = \mathbf{3096}\,J \quad \text{Eq. 4.6d}$$

$$\text{Total work}(J) = \text{Force}(N) * \text{Displacement}(m / \text{Rep}) * \#\ \text{Reps} * 1.33 \quad \text{Eq. 4.6e}$$

$$\text{Total work}(J) = \mathbf{490}\,N * \mathbf{0.5}\,m / \text{Rep} * \mathbf{9.5}\,\text{Reps} * 1.33 = \mathbf{3096}\,J \quad \text{Eq. 4.6f}$$

Power, as described in Chapter 1, expresses the *rate* at which work is done. It is calculated as work divided by time. You have probably not thought much about how much work is done during a set of 8–10 bench press exercises or at what power the exercises are done. But knowing how much work is done and knowing the time in which it is done allows the calculation of mean power. Working with the example from above, we know that completing 9.5 reps of 50 kg (490 N) over 0.5 m resulted in 3096 J of work. If the work was completed in 30.5 s, the mean power of the bench press exercise can be determined as in Equations 4.7a and 4.7b. The units end up as joules per second ($J{\cdot}s^{-1}$), which can also be expressed in watts (W) since 1 W is equal to 1 $J{\cdot}s^{-1}$.

$$\text{Mean power}(W) = \text{Work}(J) / \text{Time}(s) \quad \text{Eq. 4.7a}$$

$$\text{Mean power}(W) = \mathbf{3096}\,J / \mathbf{30.5}\,s = \mathbf{102}\,J{\cdot}s^{-1} = \mathbf{102}\,W \quad \text{Eq. 4.7b.}$$

Results and Discussion

Maximal bench press strength represents well the total upper body strength of a person. It is commonly measured by directly testing the maximal amount of weight that can be lifted in one repetition (1 RM) or estimating this value through multiple submaximal lifts. The accuracy of a submaximal, multiple repetition protocol to estimate 1 RM is improved by completing no more than about 10 repetitions to fatigue.[27] One source reports that the average free weight 1 RM bench press strength for young (18–29 y) men is

Table 4.4	Relative Bench Press Strength in College-Age Men and Women	
Category	**Men ($kg{\cdot}kg^{-1}$)**	**Women ($kg{\cdot}kg^{-1}$)**
Excellent	≥ 1.40	≥ 0.85
Good	1.20–1.39	0.70–0.85
Average	1.00–1.19	0.60–0.69
Fair	0.80–0.99	0.50–0.59
Poor	< 0.80	< 0.50

Source: Based on data adapted from Heyward (2000).[12]

Table 4.5	Absolute (Abs) and Relative (Rel) 1 RM for Bench Press in Various Groups		
Group	**Body wt (kg)**	**Abs 1 RM (kg)**	**Rel 1 RM ($kg{\cdot}kg^{-1}$)**
Untrained women[26]	61.6	28.7	0.47
Untrained women[25]	66.2	38.2	0.58
Trained women[15]	59.2	44.6	0.75
Untrained men[39]	73.1	62.8	0.86
Untrained men[25]	74.5	77.8	1.04
Trained men[39]	86.4	115.4	1.34
DII college football[42]	97.1	124.3	1.28
DI college football[38]	115.9	170.3	1.47

Source: Data from Horvat et al. (2003)[15]; Mayhew et al. (1992)[25]; Mayhew et al. (2008)[26]; Secora et al. (2004)[38]; Shimano et al. (2006)[39]; and Ware et al. (1995).[42]

66.2 kg (146 lb) and for young women is 38.6 kg (85 lb).[13] Percentiles derived from this same source allow the creation of the descriptive categories seen in Table 4.3 for evaluating bench press strength. The bench press strength of women proved to be about 60 % that of men. With increasing age, it appears that maximal bench press strength decreases about 5 % per decade from age 30 to age 50 and beyond. Prior to the 1980s, strength was not emphasized as a fitness component for middle-aged and older adults. However, due to its effect on retaining muscle mass and preserving bone density, it has attained greater importance for persons of all ages.[2,4]

Strength up to this point has been described in *absolute* terms, regardless of an individual's body weight. A person's *absolute strength* is measured by the 1 RM, described in kilograms (e.g., 1 RM = 75 kg) or pounds. It is sometimes desirable to express strength on a *relative* basis, relative to body weight. A person with a 1 RM of 75 kg with a body weight of 75 kg could be described as having a *relative strength* of 1.00. This value can be expressed with units as 1.00 $kg{\cdot}kg^{-1}$, as a ratio of 1.00 (which is unitless), or as 100 % of body weight. The benefit of describing someone's relative strength might be made clearer with the following example. Assume two people have the exact same absolute strength as defined by a 1 RM bench press of 75 kg. Further assume that one person weighs 75 kg but the other weighs 85 kg. This translates into two different relative strengths: 1.00 $kg{\cdot}kg^{-1}$ (75 kg / 75 kg) and 0.88 $kg{\cdot}kg^{-1}$ (75 kg / 85 kg). Depending on the situation, it is valuable to be able to express strength in either absolute or relative terms. Table 4.4 provides categories for evaluating relative bench press strength in untrained, college-aged men and women.[12]

Dynamic bench press strength is increased through training. Comparisons of untrained men and women with trained men and women show significant differences in absolute and relative strength, as seen in Table 4.5. Within trained participants, some groups show even greater bench press strength. Nearly every collegiate football program in the United States places great emphasis on bench press strength. Understandably, the strength developed by this particular group of athletes far exceeds the strength of the "average" person discussed throughout this chapter. The absolute 1 RM bench press strength of division II (DII) football players was nearly twice that of untrained men, and of division I (DI) players 2–3 times higher than untrained men. A more detailed description of absolute and relative bench press strength of DI college football players by position is shown in Table 4.6. Offensive and defensive linemen have the highest absolute strength, while running backs have the highest relative strength.

Table 4.6	Absolute (Abs) and Relative (Rel) 1 RM for Bench Press in College Football Players by Position		
Position	**Body wt (kg)**	**Abs 1 RM (kg)**	**Rel 1 RM ($kg{\cdot}kg^{-1}$)**
Receivers	88.7	147 ± 25	1.50 ± 0.22
Quarterbacks	94.6	156 ± 24	1.59 ± 0.23
Tight ends	114.2	168 ± 21	1.31 ± 0.17
Running backs	96.9	170 ± 25	1.65 ± 0.25
Offensive line	134.3	176 ± 26	1.39 ± 0.20
Defensive line	122.3	180 ± 24	1.49 ± 0.19

Source: Data from Secora, Latin, Berg, & Noble (2004).[38]

Although the methods for administering the test are not described in this laboratory manual, a test that is sometimes used to estimate 1 RM bench press strength in college football players is the NFL-225 test.[7,24,28,44] The test involves bench pressing 225 lb (102 kg) as many times as possible to fatigue. The number of repetitions to fatigue can then be used in a regression equation[27] to estimate 1 RM, as shown along with an example in Equations 4.7a and 4.7b. Strength tests such as these, using multiple repetitions to fatigue, instead of direct tests of 1 RM, are becoming popular with strength and conditioning specialists.[42] Essentially every lifting set to fatigue (up to 10 RM) becomes an estimate of 1 RM and time is not wasted by performing frequent maximal 1 RM tests.

Assume: Reps@225 = **10**

$$1\,\text{RM}\,(\text{lb}) = (7.1 * \text{Reps@225}) + 226.7 \qquad r = .96,\ SEE = 14.1\ \text{lb} = 6.4\ \text{kg} \qquad \text{Eq. 4.7a}$$

$$1\,\text{RM}\,(\text{lb}) = (7.1 * \mathbf{10}) + 226.7 = \mathbf{298}\ \text{lb} = \mathbf{135}\ \text{kg} \qquad \text{Eq. 4.7b}$$

As was mentioned earlier in this chapter, the tests of work and mean power were included primarily to

BOX 4.3 Chapter Preview/Review

How is isotonic or dynamic strength defined?
What does the abbreviation 1 RM mean?
How accurate is 1 RM testing?
How can 1 RM be estimated from submaximal repetitions to fatigue?
How do linear and curvilinear methods of estimating 1 RM differ?
What is the difference between absolute and relative strength?
How are work and power measured during weight lifting?
What is the NFL-225 test?

demonstrate the concept of quantifying work and power during isotonic exercise. No specific comparative data are available, so the results cannot be meaningfully evaluated. The mean power values derived from the bench press test reflect the relationship between the force (kg) generated during the lift, the distance (m) over which the force was applied, and the time (s) required to complete the lift. Interestingly, neither the highest forces nor the highest speeds necessarily produce the greatest powers. Moderate forces combined with moderate speeds most often produce the highest powers. Power during bench press exercise can be directly and accurately measured only through the use of special equipment that precisely measures force and time. When such measurements have been made, a peak power of 428 W for "explosive" bench press exercise in men was reported using a load equal to 30 % of the measured 1 RM, which was 89 $\pm$ 30 kg. Peak power decreased with heavier loads until at 90 % of 1 RM it had dropped by half, to 214 W.[40] These power values, because they are "peak power" values measured during one "explosive" bench press trial, will be much higher than any "mean power" measurements you will record during multiple submaximal bench press trials.

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