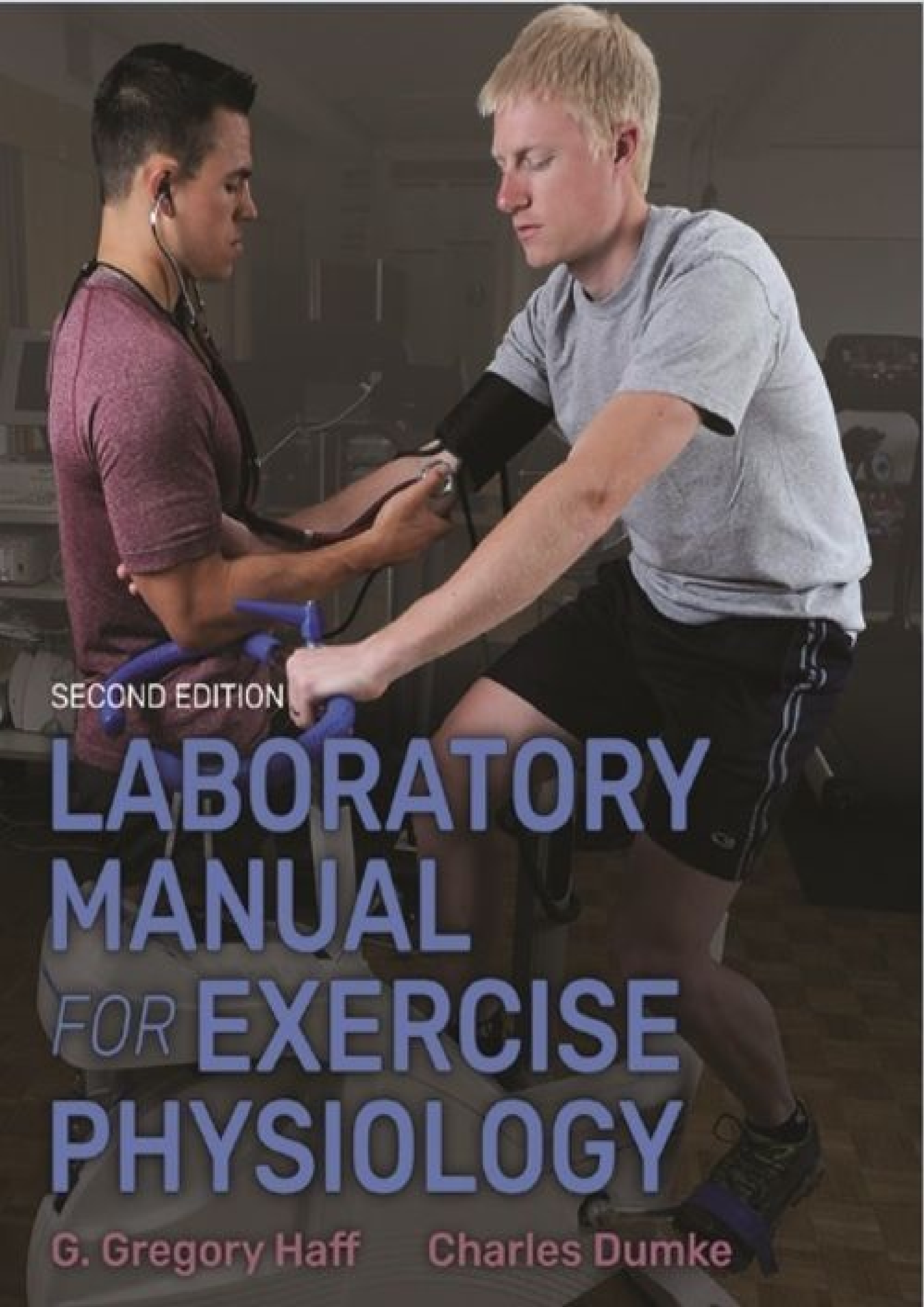
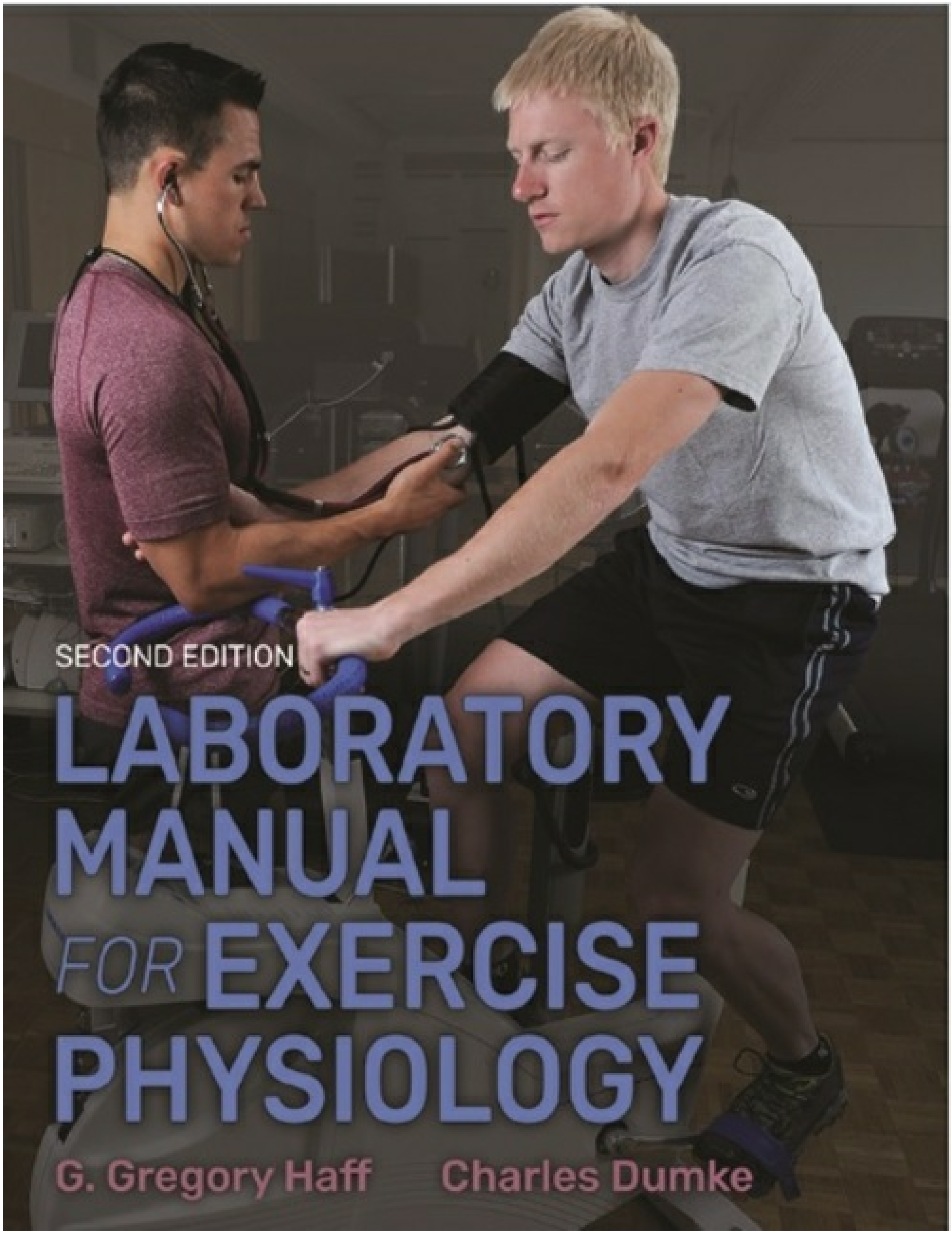


SECOND EDITION

LABORATORY MANUAL *FOR* EXERCISE PHYSIOLOGY

G. Gregory Haff Charles Dumke


SECOND EDITION
LABORATORY
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FOR EXERCISE
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G. Gregory Haff
Charles Dumke

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Laboratory Manual for Exercise Physiology

Second Edition

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Contents

Laboratory Activity Finder

Here is an alphabetical listing of the laboratory activities.

Preface

Laboratory Manual for Exercise Physiology, Second Edition, is a detailed source of tests for an undergraduate or graduate exercise physiology laboratory course. The text covers a wide variety of tests typically performed in an exercise physiology laboratory when evaluating athletes, clinical clients, or other generally healthy individuals. The design allows instructors to choose activities that best suit their course needs. Specifically, each chapter offers a wide variety of laboratory activities that can be mixed and matched depending upon the instrumentation and time allotted for your course. The range of field and laboratory tests presented here gives students broad exposure to testing that can be applied in a wide variety of professional settings. Organized in a logical progression, the labs build in complexity as students progress through the book and develop their knowledge base. Ultimately, the text serves as a resource for basic testing procedures used in assessing human performance, health, and wellness.

Updates to Second Edition

The second edition of this text brings some new and exciting updates. Perhaps the most important is the inclusion of 10 virtual laboratory activities that provide an enhanced, immersive learning experience for students. These activities, in which video is used extensively, allow students to interact with virtual lab partners, observe the proper setup and use of equipment, and participate in following test protocols in the online environment. The virtual labs align with specific aspects of the lab activities introduced in the manual, often presenting some of the more complex lab concepts.

Other updates in this second edition of the manual include laboratory activities that introduce common intermittent fitness tests such as the Léger 20 m shuttle run test, the Yo-Yo Intermittent Recovery Test, and the 30-15 Intermittent Fitness Test. These types of tests are increasingly popular in the fitness world, and their addition to the manual allows students to learn how to perform these tests and interpret their results.

In addition to these new lab activities, updates have been made to every lab in the manual:

- Added new research and information pertaining to each laboratory topic
- Updated standards and norms with new published research
- Clarified instructions
- Added new case studies to illuminate laboratory concepts
- Included answers to the case studies
- Updated question sets to help students better understand lab concepts

Special Laboratory Features

Each laboratory chapter is a complete lesson, beginning with objectives, definitions of key terms, and background information that sets the stage for learning. For each of the laboratory activities, you will find step-by-step instructions, making it easier for those new to the lab setting to complete the procedures. Each laboratory activity has a data sheet to record individual findings, as well as question sets related to the data collected by students; these questions invite students to put their laboratory experience into context.

Web Study Guide

The web study guide provides additional tools that can assist students in working through the 49 laboratory activities in the book. All laboratory activities in the book are supported by the following:

- Electronic versions of the individual data sheets from the book, which students can download to a computer or mobile device and print.
- Group data sheets, found only in the web study guide, that allow students to move beyond collecting individual data; with these group sheets, students can compile data from the entire class, calculate values such as mean and range, and compare findings to the normative data discussed in the lab.
- Downloadable versions of the question sets from the book, which can be submitted electronically, giving students an easy way to turn in answers after completing a laboratory activity.
- Practical case study questions, found only in the web study guide, that help students begin to critically analyze data collection and synthesize it with material they have learned in lecture and other courses. The case studies are provided as downloadable electronic files that students can complete and submit online.

In addition, 10 of the laboratory activities are provided as interactive labs, all of which include video, that give students an approximation of the real-world experience of performing the lab activities. These interactive labs complement the laboratory manual. This sentence identifies the 10 interactive labs:

> This laboratory activity is supported by a virtual lab experience in the web study guide.

The web study guide is available at www.HumanKinetics.com/LaboratoryManualForExercisePhysiology.

Instructor Ancillaries

An image bank is available for instructor use. The image bank includes most of the figures, tables, and photos from the book, saved as individual files. Instructors can use these items to create a PowerPoint presentation, enhance lecture notes, create student handouts, and so on. Instructors also have full access to the web study guide, and they have access to the cases study answers.

Notes for Instructors

This manual is geared toward use in an exercise physiology laboratory course. It is designed to translate the scientific foundation developed in a core exercise physiology lecture course —using, for example, a text such as *Physiology of Sport and Exercise* by Kenney, Wilmore, and Costill (Human Kinetics, 2016)—into practical applications typically performed in a variety of settings. To accomplish this goal, the manual is divided into 16 laboratories that lead students through a series of activities: primary data collection, pretesting screening, flexibility testing, blood pressure measurements, resting metabolic rate, oxygen deficit and EPOC evaluations, submaximal exercise testing, aerobic power field assessments, high-intensity fitness testing, maximal oxygen consumption measurements, blood lactate threshold assessment, musculoskeletal fitness measurements, anaerobic fitness measurements, pulmonary function testing, body composition assessments, and electrocardiograph measurements.

Each laboratory provides background information and detailed step-by-step procedures for a variety of tests. In addition, because exercise physiology laboratories are equipped in various ways, the labs present multiple methods for introducing the testing concept. For example, laboratory 13 presents multiple methods for assessing vertical jump performance: jump and reach, Vertec, and switch mat. Equipment lists at the beginning of each activity make it easier to choose the labs that will work best in your facility. This versatility enables you to choose activities that best fit your facilities and best meet the needs of your students.

Acknowledgments

I would like to thank Human Kinetics for their patience with Chuck and me as we slogged through the writing of the second edition of this text. Specifically, I would like to thank Roger Earle for his belief in our abilities and, more importantly, for his friendship. Additionally, I would like to thank Amy, Lisa, and Amanda for working tirelessly to assist us in updating this text to improve upon our first edition.

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To my friends Michael Stone, Duncan French, Joel Cramer, Jay Dawes, and Travis Triplett, I am honored to call you my friends, and you each impact my life more than you know. I look forward to enjoying life in your company.

Finally, I would be remiss if I did not acknowledge the most important person in my life—my wife, Erin. You are the rock that supports me in all endeavors that I undertake. While things never seem to go smoothly or appear to be working out, your ability to ground me and to make me laugh, stop, and watch the waves is more than anyone could ever want in a life partner. I am blessed to have you in my life.

—*Greg Haff*

Thanks to Greg for being a great coauthor and friend. I wouldn't have wanted to do this by myself or with anybody else. Human Kinetics deserves a shout-out for their experience, professionalism, and patience with our ideas and extension of deadlines. Thank you for taking this book to product and being open to creative ideas for the second edition.

I would also like to thank my colleagues in the department of health and human performance at the University of Montana for their patience with me as I worked on this project.

Most importantly, thank you to my parents, Bob and Leah, and to my wife, Shannon; son, Carter; and dog, Rastro.

—*Chuck Dumke*

Laboratory 1
Primary Data Collection

Objectives

- Define basic terminology associated with testing.
- Learn metric conversions and the units recommended by the International System of Units (SI).
- Provide a rationale for collecting basic information during testing.
- Present the methods for evaluating temperature, barometric pressure, and relative humidity.
- Present basic statistical methods for evaluating test results.
- Describe types of graphics for presenting data.

Definitions

accuracy—Degree of a measurement's closeness to the actual value.

barometric pressure—Pressure exerted by ambient air.

central tendency—Score that best represents all scores collected for a group.

dependent variable—Effect or yield of the independent variable.

displacement—Length that an object moves in a straight line between two points.

distance—Total length that an object travels (may or may not be in a straight line).

effect size—Statistical method used to determine the magnitude of an effect.

energy—Capacity to do work, expressed as a joule (J).

field/laboratory test—Test that can be completed in either a field or a laboratory setting.

field test—Test completed in a field setting.

force—Mass multiplied by acceleration, expressed as a newton (N).

independent variable—Variable that is manipulated.

inferential statistics—Statistical methods that can be used to draw general conclusions about a population based on a population sample.

laboratory test—Sophisticated test that must be conducted in a laboratory setting.

magnitude statistics—Statistical methods that can be used to evaluate the magnitude of change, typically using the smallest worthwhile change or effect size.

mass—Measure of matter that constitutes an object; expressed in kilogram (kg).

mean—Average score of a sample.

median—Middle score of a sample.

mode—Most frequent score of a sample.

normative data—Placement within a population; also referred to as *norms* or *norm* *data*.

power—Rate at which work can be performed, represented as a watt (W).

precision—Degree to which a test is reproducible with nearly the same value.

range—Distance between end points in a group of scores.

relative humidity—Amount of water or percent saturation in ambient air.

reliability—Repeatability of a measure.

smallest worthwhile change—Smallest practically important change in some measure.

speed—Scalar quantity generally considered to be how fast a body is moving; calculated by dividing distance covered by time.

standard—Desirable or target score.

standard deviation (SD)—Measure of variability that shows variation or dispersion from the mean.

typical error (TE)—The most common measure of reliability; calculated as the standard deviation of the change scores between repeated measures divided by $\sqrt{2}$.

validity—Accuracy of a measure.

variability—Spread of a data set.

variable—A characteristic.

velocity—Vector quantity calculated by dividing displacement by time.

wet-bulb globe temperature (WBGT)—Measure of temperature that estimates cooling capacity of the surrounding environment.

work—Force times the distance through which it acts.

z-score—Standardized score indicating the distance of an individual score in standard deviation units from the mean of a group.

Testing human performance under exercise conditions allows for the evaluation of the human body's functional ability. This information can give us an understanding of the individual's overall health and wellness as well as athletic performance capacity. We can also garner information about the ability to tolerate and adapt to exercise by examining the individual's postexercise responses. This information can then be used to implement exercise programs designed to enhance health and wellness or sport performance. There are numerous tests that can be performed in the exercise physiology laboratory in order to evaluate health and wellness (1, 6, 21, 31) or examine athletic performance capacity (27, 38). Many of these tests fall into one of three classifications: field, field/laboratory, and laboratory.

Field tests allow us to assess specific fitness and performance variables in a real-world setting (16). These tests are generally practical and less expensive than their laboratory-based counterparts (32). Though not often used for research due to difficulty in controlling external variables (e.g., weather, terrain), these tests are extremely useful for screening and monitoring purposes (6). Because these tests are developed from their laboratory counterparts, they can offer a high degree of validity when conducted with attention to appropriate methodological controls. Examples in exercise physiology include the 1 to 1.5 mi (1.6-2.4 km) run test, the 1 mi (1.6 km) jogging test, the 12 min cycling test, sprints, the 30-15 Intermittent Fitness Test (11), and the quantification of the body mass index, or BMI (3, 10). Though typically done in field settings, some of these tests may also be conducted in laboratory settings (e.g., BMI, 12 min cycling test).

Field/laboratory tests can be conducted in either field or laboratory settings. Like field tests, they often require minimal equipment, but they are subjected to tighter controls (6), and a field/laboratory test in the field must be performed with the same tight controls that would be used in the laboratory (3). One example of a field/laboratory test is the step test (6). In the laboratory, this test can be performed using a step box, which limits the number of subjects to one. In the field, the step test can be performed on stadium bleachers with a large number of subjects at the same time. Regardless of location, the step test requires a metronome and stopwatch to appropriately conduct and control the test. Other examples of field/laboratory tests include the sit-and-reach test, skinfold assessments, vertical jump testing, and blood pressure (BP) measurements (6).

Laboratory tests are conducted with the highest level of control and often require expensive equipment that cannot be taken into the field; as a result, they are usually performed on one person at a time (6) and thus tend to be time consuming. In return, they offer a significantly higher degree of accuracy and precision (6). Examples include measurement of maximal oxygen consumption, quantification of resting metabolic rate (RMR), exercise electrocardiograms (ECGs), dual X-ray absorptiometry (DXA), underwater weighing (UWW), quantification of isometric or dynamic force-time curves, and anaerobic treadmill testing (4-6, 12).

Test Variables

A central goal in the exercise physiology laboratory is to quantify specific physiological or performance characteristics. A characteristic is usually termed a variable. Variables often quantified in an exercise physiology laboratory include maximal strength, body composition, anaerobic or aerobic power, and flexibility.

Variables are generally categorized as either independent or dependent. The independent variable is the one that is manipulated, whereas the dependent variable is the effect of, response to, or yield of the independent variable (39). In other words, the independent variable is controlled by the person administering the test, and the dependent variable is the physiological or performance response to the independent variable. In a treadmill test, for example, the independent variable is the speed of the treadmill; the dependent variable is the heart rate (HR) response or oxygen consumption rate. When graphically representing these variables, we place the independent variable on the *x*-axis (horizontal axis) and the dependent variable on the *y*-axis (vertical axis) (39). In the example of the treadmill test, then, the workload or speed would be the independent variable presented on the *x*-axis, and the HR response would be the dependent variable presented on the *y*-axis.

Measurement Terminology

When examining physiological and performance characteristics, exercise physiologists use specific measurement terminology to discuss their data. This terminology is based on the guidelines set forth in the Système International d'Unités, or International System of Units (SI) (42). This system is designed to adhere to the core principles of being simple, precise, and accurate (table 1.1).

Table 1.1 Sample SI Units

Unit	Name	Symbol
	BASE SI UNITS	
Amount of substance	Mole	mol
Electric current	Ampere	A
Length	Meter	m
Mass	Kilogram	kg
Thermodynamic temperature	Kelvin	K
Time	Second	s
	DERIVED UNITS	
Energy	Joule	J
Force	Newton	N
Frequency	Hertz	Hz
Power	Watt	W
Pressure	Pascal	Pa
Work	Joule	J

Following are some examples of common terms used in the exercise physiology laboratory.

The most common measurements of mass performed in the exercise physiology laboratory are measurements of body mass, lean body mass, and fat mass. Though the terms *body mass* and *body weight* are often used interchangeably in the United States, it is more accurate to use the term *body mass*. The SI base unit for mass is the kilogram (kg) (42).

Force is a vector quantity characterized by both magnitude and direction. It can be calculated according to Isaac Newton's second law, which states that force is equivalent to mass multiplied by acceleration (29):

$$\text{Force} = \text{mass} \times \text{acceleration}$$

For example, body mass is used often in this laboratory manual when calculating work or work rate, and in such instances body mass is converted to newtons and used in other calculations. Forces are generally expressed as newtons (N), which are calculated by multiplying the object's mass in kg by its downward acceleration due to gravity:

$$\text{Force (N)} = \text{mass} \times \text{acceleration} = \text{mass (kg)} \times 9.81 \text{ m} \cdot \text{s}^{-2}$$

When thinking about force, it is not uncommon to consider the expression of strength. Generally, strength is the maximal force generated by a muscle or group of muscles at a specific velocity or the ability to generate external force (29). Such capability often constitutes a major concern. Force-generating capacity plays an important role in the ability to perform in sport (10) and activities of daily living (22). In addition, the ability to repetitively express submaximal forces is important in endurance activities. Thus strength, or force-generating capacity, exerts a major effect on athletic performance and overall fitness.

Both displacement and distance can be considered as lengths. Displacement is measured in a straight line from one point to another, whereas distance is the total length that an object travels and may or may not be limited to a straight line. Both are typically measured in centimeters or meters, but the meter is the SI base unit. Quantification of displacement and distance contributes to calculations such as work, velocity of movement, and expression of power.

To calculate the amount of work completed, multiply the amount of force exerted on an object by the distance that the object is moved:

$$\text{Work (J)} = \text{force (N)} \times \text{distance (m)}$$

The results of this equation are reported in joules (J; the SI unit for work), which is equal to newton × meters ($N \cdot m$). As a whole, work is directly related to the amount of metabolic energy expended—the more work performed, the more kilocalories used (28, 37).

It is important to differentiate between speed and velocity. Speed is a scalar quantity generally considered to be how fast a body is moving, which is directly related to the total distance covered divided by time. Though similar to speed, velocity is an actual vector that has a magnitude and a direction. Therefore, velocity is based on both speed and direction (26). The difference between speed and velocity centers on the difference between distance and displacement. Mathematically, speed is calculated by dividing distance by time, whereas velocity is calculated by dividing displacement by time:

$$\text{Speed} = \text{distance} / \text{time}$$

$$\text{Velocity} = \text{displacement} / \text{time}$$

For example, a runner who completes a 400 m dash in 49 s would have an average velocity of $0\ m \cdot s^{-1}$ because the displacement would be zero. In this instance, then, it would be better to use average speed to represent how fast the runner is moving, and the result would be $8.16\ m \cdot s^{-1}$.

Velocity is the linear speed of the object, distance represents how far the object has moved in a given direction, and time represents how long it took to cover that distance (26). For example, if a 100 m sprint was run in 9.58 s, the average velocity of the event would be $10.4\ m \cdot s^{-1}$.

Power is the rate at which work can be performed (37, 41), and the ability to express high power outputs is one of the most important factors in sport performance (8). Power can be calculated in several ways:

$$\text{Power} = \text{work} / \text{time}$$

$$= \text{force} \times \text{velocity}$$

$$= \text{force} \times (\text{displacement} / \text{time})$$

Power is generally proportional to the amount of energy used (37)—thus, the higher the power output, the higher the work rate, which corresponds to a faster expenditure of energy. Because of this relationship, power is often used when discussing the transfer of metabolic energy to physical performance (24, 25). For example, power is used to describe this transformation when talking about aerobic power and anaerobic power.

In a general sense, energy is the capacity to do work (9), and it is often represented in joules. When examining metabolic energy release—the result of work done (energy used) and heat released (energy wasted)—the joule is the universally accepted unit (6). In the United States, however, it is more common to represent this release as kilocalories (kcal).

It is possible to estimate caloric or kilojoule (kJ) expenditure by determining oxygen uptake and cost. It can be assumed that 1 liter (L) of oxygen uptake corresponds to approximately 5 kcal or 21 kJ of energy expenditure. Thus, caloric expenditure can be calculated with one of the following formulas (3):

$$\text{Energy expenditure (kcal} \cdot \text{min}^{-1}) = \text{oxygen uptake (L} \cdot \text{min}^{-1}) \times 5\ (\text{kcal} \cdot \text{L}^{-1})$$

$$\text{Energy expenditure (kJ} \cdot \text{min}^{-1}) = \text{oxygen uptake (L} \cdot \text{min}^{-1}) \times 21\ (\text{kJ} \cdot \text{L}^{-1})$$

These figures are only approximations, and they can be influenced by the intensity of exercise. Specifically, higher intensities result in more energy being expended per liter of oxygen consumed (6).

Metric Conversions

The use of metric units is standard in most exercise physiology laboratories. Though the metric system is not popular in the United States, it is the preferred system when conducting testing and research. Laboratory work in exercise physiology typically involves three categories of conversion: length, weight, and volume.

The standard metric and SI unit for length in scientific publications is the meter; it is generally used when reporting a person's height. The meter is easily converted to other metric units, such as the millimeter, centimeter, and kilometer (e.g., 0.01 km = 10 m = 1,000 cm = 10,000 mm) (see appendix A). To convert from the American system to the metric system, simply multiply length in inches by 2.54 to figure the length in centimeters. A more complete list of conversions can be found in appendix A.

When referring to weight, the base metric and SI unit is the kilogram (kg), which is the preferred method for representing mass in scientific literature (40, 42). In the exercise physiology laboratory, it is common to represent body mass, lean body mass, and fat mass in terms of kilograms (3). The conversion of pounds to kilograms is easily accomplished by dividing the pound weight by 2.2046. A summary of basic conversions for measurements of mass can be found in appendix A.

The basic metric unit for volume is the liter, also known as a cubic decimeter (dm^3) (40). The SI unit for volume is the cubic meter (m^3) because it can be used to express the volumes of solids, liquids, and gases (40, 42). For example, 0.0015 m^3 is equivalent to 1,500 mL or 1.5 L (appendix A). The liter is commonly used when quantifying lung volume, oxygen consumption, cardiac output (CO), stroke volume (SV), and sweat loss. Length and weight measures can also be converted easily to volume measures. For example, if an athlete loses 1 kg of body mass during a training session, this is equivalent to 1 L of sweat loss and thus would require >1 L of water to restore fluid balance (6). A summary of volume conversions can be found in appendix A.

Background and Environmental Information

Collecting basic information is an important organizational part of the testing process (3, 6). In planning a testing session, you should consider several distinct items as part of the basic information collected—for example, the subject's name or identification number, age, and sex. It is also important to note the date, time of day, and who conducted the testing session.

- *Name or identification number:* Typically, the subject's surname is noted first, followed by a comma and the subject's first name; however, if the data are being used for research, a subject number should be noted instead of the subject's name in order to ensure confidentiality and compliance with research procedures for human subjects (7). This information is generally placed at the top of each data sheet and on all forms related to the test.
- *Age and sex:* It is crucial to note the subject's age, especially when comparing the subject's data with those presented in normative data tables. The subject's age is typically recorded to the nearest year, though some instances may warrant reporting the year to the closest tenth of a year (3, 6). For example, if a subject is 18 years and 6 months old, the age should be recorded as 18.5 years. It is also necessary to document the subject's sex, generally by recording an *M* for male or an *F* for female on the data sheet.
- *Date:* The date should be recorded as either month/day/year or day/month/year. For example, the date of March 3, 2018, could be noted as 3/3/2018 in the appropriate location on the laboratory data sheet. This information should be clearly noted on any data sheet used in the testing process (3, 6).
- *Time:* It is especially important to note time when performing longitudinal testing because some biological and performance measures exhibit diurnal or circadian variations (10, 35, 36). As a result, longitudinal testing sessions should generally be conducted at the same time each day in order to minimize the possibility of diurnal- or circadian-induced variations in performance.
- *Tester's initials:* The tester should initial the data sheet to create a record of who conducted the testing session (6). This information identifies a contact person to whom one can direct questions about the session. It also enables you to match the subject and tester if differences arise between testers in the facility.

In testing procedures in the exercise physiology laboratory, the two basic variables most often assessed are height and weight. These measures can serve simply as descriptors or as integral parts of a testing program.

Height, technically referred to as *stature*, is routinely measured in most exercise physiology laboratories. Stature is generally measured with a physician's scale, a stadiometer, or a metric scale attached to a wall (6). The measurement should be made to the nearest tenth of a centimeter (0.1 cm) or to the nearest quarter or half of an inch (.25-.5 in.) and then converted to meters. For example, if stature is determined to be 5 ft 11 in., the following conversion would be made:

$$\text{m} = \text{in.} \times 0.0254$$

$$\text{Stature in m} = 71\ \text{in.} \times 0.0254 = 1.8034\ \text{m}$$

Rounding to the nearest hundredth of a meter, 1.8034 m would be reported as a value of 1.80 m. Similarly, if the height had been calculated as 1.8288 m, the reported value would be rounded to 1.83 m.

The assessment of weight is probably the most common test in the exercise physiology laboratory because it plays a role in many calculations. Body weight, which is equivalent to body mass under normal gravitational forces (6), is represented as a kilogram value in the scientific literature. Most Americans are familiar with pound measurements, but this representation of weight does not meet SI standards. To convert body mass from pounds to kilograms, use the following equation:

$$\text{Mass (kg)} = \text{mass (lb)} / 2.2046$$

Every 1 kg is equal to 2.2046 lb, a figure that is more commonly expressed as 2.2 lb. If a person weighs 225 lb, body mass would be calculated as follows:

$$\text{Mass (kg)} = 225\ \text{lb} / 2.2046 = 102.1\ \text{kg}$$

If this equation were used with 2.2 lb in the denominator, then the individual's body mass would be recorded as 102.3 kg. Body mass results should be rounded to the nearest tenth of a kilogram.

Once you have recorded the background information, the next step is to measure and record meteorological information about the testing environment. Typically, you will assess temperature, barometric pressure, and relative humidity (6) because they can profoundly affect the results of certain physiological and performance tests (14, 28, 33). It is well documented that high temperature can exert a significant physiological effect on test results (14, 33). In fact, it appears that HR increases 1 beat per minute (beats · min^{-1}) for every increase of 1 °C above 24 °C (33). In contrast, cold environments can increase the respiratory rate, which can negatively affect performance by increasing the risk of dehydration.

Temperature is commonly represented in units of Fahrenheit, Celsius, or Kelvin (40). Most Americans are familiar with the Fahrenheit temperature scale, in which 32 °F represents the melting point of ice (6), but this measure is not recommended by the international system

(SI) that sets the standard in research settings (40).

Another common method for representing temperature is the Celsius scale, in which 0 °C represents the freezing point of water and 100 °C represents the boiling point (6, 16). To convert from Fahrenheit to Celsius, use either of the following formulas:

$$°C = (°F - 32) / 1.8$$

$$°C = 0.56 \times (°F - 32)$$

This measure of temperature is commonly seen in the scientific literature, but, like Fahrenheit, it is not the recommended SI unit (42). Instead, the SI thermal unit is the Kelvin (K), which contains no negative or below-zero temperatures. The conversion from Celsius to the Kelvin scale is accomplished by the following formula:

$$K = 273.15 + °C$$

This system represents the coldest possible temperature as 0 K (6).

The pressure of ambient air is represented as barometric pressure and can fluctuate with changes in altitude (23) and weather pattern (6). As barometric pressure changes, so do the partial pressures of the gases that make up ambient air (oxygen, carbon dioxide, and nitrogen). Regardless of the change in overall barometric pressure, the percentage of the gases contained in the ambient air remain constant. Ambient air contains 79.04% nitrogen (N_2), 20.93% oxygen (O_2), and 0.03% carbon dioxide (CO_2). In order to determine the partial pressures of these gases, simply multiply the total barometric pressure by the percent contribution of the gases.

Barometric pressure is measured with an aneroid or mercury barometer in units of millimeters of mercury (mmHg). For example, at sea level, barometric pressure is about 760 mmHg, and the partial pressure of oxygen is around 159 mmHg. At an elevation of 2,000 m above sea level, the barometric pressure would fall to about 596 mmHg, whereas the partial pressure of oxygen would decrease to 125 mmHg. This reduction in barometric pressure and concomitant decrease in the partial pressure of oxygen can result in a significant decrease in the ability to perform aerobic exercise (18, 28). Because of the impact of changes in barometric pressure on both pulmonary and cardiovascular function, both respiratory ventilation and metabolic volumes are often corrected for these changes (6).

In the scientific literature, barometric pressure is typically reported in the following units: mmHg, torr, hectopascal (hPa), or kilopascal (kPa). Generally, the following formulas can be used to convert the various units:

$$1 \text{ torr} = 1 \text{ mmHg}$$

$$kPa = torr \times 0.1333 = torr / 7.50$$

$$hPa = torr \times 1.333 = torr / 0.750$$

Therefore, a barometric pressure of 674 mmHg or 674 torr would be converted as follows:

$$674 \text{ torr} \times 0.1333 = 89.8 \text{ kPa}$$

$$674 \text{ torr} \times 1.333 = 898.4 \text{ hPa}$$

The relative humidity of the environment is the amount of water or percent saturation in the ambient air (6, 23). To quantify relative humidity in the exercise physiology laboratory, use an instrument called a *hygrometer*, which yields a percent relative humidity value (e.g., 60% relative humidity). If, for example, the ambient air is completely saturated with water vapor, then the relative humidity is represented as 100% at that temperature. Generally, the amount of water that can be contained in ambient air increases with temperature.

Relative humidity values between 20% and 60% generally do not affect exercise, but values above or below this range can influence physical performance (2). Specifically, high humidity limits the evaporative capacity of sweat, which can significantly reduce blood plasma volume and thus increase cardiovascular stress. High relative humidity can also affect thermoregulation, which can increase the effects of temperature on cardiovascular function (28). Instead of the 1 beat · min^{-1} increase in HR typically associated with a 1 °C increase in temperature above 24 °C, an increase in relative humidity can result in a 2 to 4 beats · min^{-1} increase in HR (6, 33). Because of these potential effects on physical performance, relative humidity is commonly assessed in the exercise physiology laboratory.

Heat stress can be estimated in terms of the wet-bulb globe temperature (WBGT). This measure simultaneously accounts for three thermometer readings and provides a single temperature reading to estimate the cooling capacity of the surrounding environment (23). The first thermometer measurement is the dry-bulb temperature (T_{db}), which is taken with a standard thermometer and evaluates the actual air temperature. The second thermometer measurement is taken with a wet-bulb thermometer, which reflects the effect of sweat evaporating from the skin (23). With this measure, water evaporates from the bulb, which effectively lowers the temperature below that represented by the dry bulb, thus yielding the wet-bulb temperature (T_{wb}). The difference between the wet- and dry-bulb temperatures represents the environment's capacity for cooling. The third thermometer is placed in a black globe and generally has a higher temperature than that indicated by the dry bulb because the black globe absorbs heat. This globe temperature (T_g) is used to estimate the radiant heat load of the environment (23).

Once the temperature has been measured with the three thermometers, the three results can be combined to estimate the overall atmospheric challenge to body temperature in outdoor environments using the following equation:

$$WBGT = 0.1T_{db} + 0.7T_{wb} + 0.2T_g$$

Careful examination of this equation reveals that the T_{wb} reflects the importance of sweat evaporation in the physiology of heat exchange. If the relative humidity is high, this measure reflects impairment in the ability to evaporate sweat, which in turn increases the heat load encountered by the body (23). As a general rule, if the WBGT is >28 °C (>82-83 °F), then modifications to exercise or practice should be considered—including canceling practice, moving to indoor facilities, or reducing the training intensity.

Descriptive Statistics

Statistics are a mathematical method for describing and analyzing numerical data (39). Exercise physiology laboratories typically involve calculating descriptive statistics such as measures of central tendency and variability.

Central Tendency

Measures of central tendency are commonly used to present a score that best represents all of the scores collected for a group (39). The most common statistics calculated when representing central tendency are the mean, median, and mode. The mean is calculated by summing all the scores and dividing the result by the number of scores. The following formula represents the calculation of the mean:

$$\text{Mean} = \frac{\Sigma X}{N}$$

In this equation, X is the individual scores, and N equals the number of scores. For example, if you measured the body mass of five people as 53, 55, 65, 48, and 60 kg, the mean would be calculated as follows:

$$\text{Mean} = \frac{53+55+65+48+60}{5} = \frac{281}{5} = 56.2 \text{ kg}$$

Therefore, for this example, the mean weight for the five individual tests is 56.2 kg.

The median represents the middle score in a series of data. It is generally calculated using the following equation when the sample is placed in order:

Median = [(N + 1) / 2]th score

In this equation, N represents the total number of scores in the sample. For the preceding example involving five body weights—now placed in order as 48, 53, 55, 60, and 65 kg—the median would be calculated as follows:

Median = (5 + 1) / 2 = 3rd score

You would then count 3 places from the first score, thus revealing the median as 55 kg. If trying to calculate the median with an even number of values, you need to first find the middle pair of numbers. For example, if the six weights are 48, 53, 55, 58, 60, and 65 kg, the preceding equation would give (6 + 1) / 2 = 3.5. You would then move in 3.5 positions and find the two middle values, 55 and 58. These would be added together, 55 + 58 = 113, and then divided by 2, which yields a median value of 56.5.

The mode is the most frequent score in a sample, and it is possible to have more than one mode in a group of scores. If the body masses of 10 people were measured as 48, 49, 53, 53, 55, 59, 60, 60, 60, and 62 kg, the most frequently occurring value would be 60 kg, which would thus be identified as the mode of this sample population. If each score in a sample appears with the same frequency, then the mode is undefined for that sample.

Variability

The variability of a data set allows the spread of the data to be depicted. In examining a group of data in the exercise physiology laboratory, variability is commonly examined with the use of the standard deviation and the range.

The standard deviation (SD) of a data set is easily calculated by many spreadsheet programs, but it can also be calculated by hand with the following equation:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma(X - M)^2}{(N - 1)}}$$

In this equation, the mean (*M*) is subtracted from each score (*X*) in the group. The result for each score is then squared, and these figures are summed to provide a total, which is then divided by the number (*N*) of scores in the group minus 1. The square root of this is the standard deviation. An example of how one might calculate the standard deviation is presented in the accompanying highlight box; the example involves body mass measurements of five subjects.

Sample Calculation of Standard Deviation

Sample Laboratory Data Table

Sample	X	$X - M$	$(X - M)^2$
1	53	−3.2	10.2
2	65	8.8	77.4
3	48	−8.2	67.2
4	60	3.8	14.4
5	55	−1.2	1.4
Σ =	281	0.0	170.8

$$\text{Mean} = \frac{\Sigma X}{N} = 281 / 5 = 56.2$$

$$\text{SD} = \sqrt{\frac{\Sigma(X - M)^2}{(N - 1)}} = \sqrt{\frac{170.8}{4}} = \sqrt{42.7} = 6.53$$

Note: SD = standard deviation; X = sample score; M = mean; N = number of samples.

Thus the mean body mass was 56.2 kg, and the standard deviation was 6.53 kg. In a results section of a manuscript or laboratory report, we would then represent these data as 56.2 ± 6.5 kg.

If the standard deviation and the mean of a group are calculated, a z-score can be determined in order to express the distance of any individual score in standard units from the mean (30):

$$z = \frac{\text{sample score} - \text{group mean}}{\text{group standard deviation}}$$

For example, if a group of weightlifters were tested in the isometric midthigh pull, and the group average peak force was 3013.9 N and the group standard deviation was 360.7 N, then the z-score for an athlete who had a peak force of 2679.7 would be calculated as follows:

$$z = \frac{2679.7 - 3013.9}{360.7} = \frac{-334.2}{360.7} = -0.93$$

This athlete’s performance on the test would then be −0.93 standard deviations below (i.e., weaker) than the group tested.

The second measure of variability often used in the exercise physiology laboratory is range —the distance between the end points in a group of scores (7). The range is easily calculated with the following formula:

$$\text{Range} = (\text{high score} - \text{low score}) + 1$$

Thus, for our previous example of body mass scores, the range would be calculated as follows:

$$\text{Range} = (65 - 48) + 1 = 17 + 1 = 18$$

The high score can also be considered as the *maximum,* and the low score would be considered as the *minimum*. These variables are also sometimes reported in the results generated by performance testing in the exercise physiology laboratory.

Reliability and Validity

Whether you are conducting basic testing or using test results for research purposes, it is essential to determine the reliability and validity of the testing process. If the tests chosen do not meet both of these criteria, you may produce false information about the subject's physiological or physical performance capacity. Therefore, before using any testing procedure—whether in the field or laboratory—you must determine its reliability and validity. Typically, you can do so by using established testing protocols that have been previously validated and determined to be reliable.

Reliability refers to the repeatability or consistency of a measure (7, 19, 39). The reliability of a measure is often affected by experimental or biological errors (6). Experimental errors may include technical errors such as miscalibration of instruments or changes to the testing environment. Biological errors may include natural shifts in performance that occur in response to the time of day when testing is undertaken (35, 36) or in response to accumulated fatigue. The subject's familiarity with the testing process can also affect reliability (6). Therefore, when introducing new testing procedures, it is important that athletes and clients are adequately familiarized with the tests. This can be done via several practice trials before the start of the actual testing session.

Statistically, the primary methods for evaluating reliability are the change in the mean between measurements, the standard error of the measurement, and the intraclass correlation coefficient (ICC) (34). Highly reliable field, field/laboratory, and laboratory tests generate high ICCs and low coefficients of variation (CVs) when repeated trial data are compared (6, 19). Acceptable ICCs range between 0 and 1 or between 0 and −1. Perfect correlations are either 1 or −1 (4); they rarely occur with the variables analyzed in the exercise physiology laboratory. Generally, correlations greater than 0.90 demonstrate high reliability, whereas correlations less than 0.70 exhibit poor reliability (6). The most common reliability measure is the typical error (TE) of the measurement. The typical error is calculated by dividing the standard deviation of the change scores between repeated measures divided by the square root of 2 (34).

Sample Reliability and Error Calculations

Subject	Trial 1	Trial 2	ΔT2-T1	100*LN(T1)	100*LN(T2)	ΔT2-T1
1	2679.7	2684.0	4.3	789.3	789.5	0.2
2	2775.1	2752.3	−22.8	792.8	792.0	−0.8
3	3600.5	3609.2	8.6	818.9	819.1	0.2
4	2751.7	2979.0	227.3	792.0	799.9	7.9
5	3258.3	3170.7	−87.6	808.9	806.2	−2.7
6	3297.2	3222.8	−74.4	810.1	807.8	−2.3
7	2897.2	3093.2	196.0	797.2	803.7	6.5
8	2452.9	2453.9	0.9	780.5	780.5	0.0
9	3069.2	3043.6	−25.7	802.9	802.1	−0.8
10	3357.1	3356.3	−0.8	811.9	811.9	0.0
Mean	3013.9	3036.5	22.6	800.5	801.3	0.8
SD	360.7	339.0	105.1	12.0	11.4	3.5
Reliability in raw values				Reliability as a percentage of log transformation		
Change in mean		22.6		Change in mean %		0.8
TE		74.3		TE as a CV (%)		2.5
ICC		0.96		ICC		0.97

Note: TE is calculated as the SD of the change score divided by √2. In this example, TE = 105.1 / √2 = 105.1 / 1.414 = 74.3. LN = natural logarithm; SD = standard deviation; TE = typical error; ICC = intraclass correlation coefficient; CV = coefficient of variation.

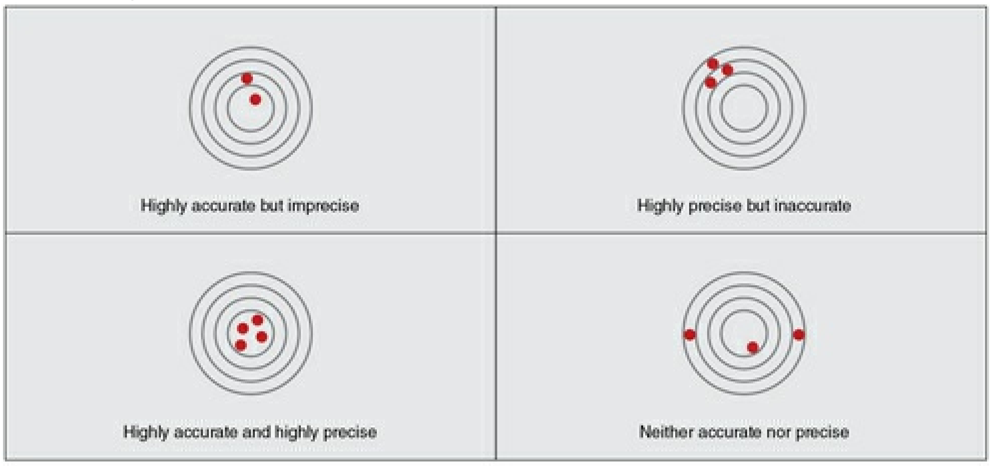
Generally, the smaller the TE, the more reliable the measure. With performance-based measures, the general marker of reliability is an ICC >0.80 and a CV (%) <10.0 (15).

Even if a measure or test is reliable, it may not be valid; in other words, rather than providing a suitable assessment of what you are trying to measure, your measures might be dependable but consistently wrong. Therefore, you must determine that a test is both reliable and valid before using it in a clinical or sport testing program.

Validity is the degree to which a test or instrument measures what it is supposed to measure (39). In the exercise physiology laboratory, the main form of validity is criterion validity—the ability of a test to be related to a recognized standard or criterion measure (39). For example, when examining body composition, UWW is considered the gold standard or criterion measure. When considering another method of assessing body composition—say, skinfold measurements—validity is determined by correlating the results obtained from the skinfold estimate to the body fat as determined by underwater weighing. Typically, this correlation is performed with the use of a Pearson product-moment correlation coefficient, and a high correlation (*r*) between the criterion variable and the test represents high validity.

A measurement is considered valid if it is both accurate and precise. The closer a measurement is to an accepted value, the higher the accuracy of the measurement. For example, if multiple arrows are shot at a target, the closeness of the arrows to the bull's-eye indicates the accuracy of the measure. If the arrows are clustered close to one another, then there would be a high degree of precision. Thus, precision is considered to be the reproducibility of the measurement. Ultimately, a measure can be highly accurate but not precise, highly precise but not accurate, highly accurate and highly precise, or neither highly precise nor highly accurate (see figure 1.1).

Figure 1.1 The relationship between accuracy and precision.



Presentation of Results

Data collected on a group of subjects can be presented in many ways in a publication or laboratory report. One of the first steps in determining how to present data is to decide whether it should be placed in a table, a figure, or the text of the document. Consider whether you can best represent the information in the form of the actual numbers collected or as a picture of the results. Once you make this decision, you can create a table or figure to best represent the data.

Though it is relatively easy to create a table with modern software, it remains important to consider some basic rules. First, tables provide a means for communicating information about data—not storing them (39). For example, a good use of tables is creating normative data tables for evaluating testing. You can use these tables for communicating information about typical results for any given field or laboratory test. When creating a table, follow these rules suggested by Thomas, Nelsen, and Silverman (39):

- Table headings should be clearly labeled and easy to follow. To improve readability of headings, avoid excessive abbreviation and make formatting easy to follow.
- Like characteristics should be presented vertically. The columns and rows contained in the table should make sense. For example, columns could contain variables, means, and standard deviations, and each row could represent a specific variable.
- Readers should not have to refer to the text to understand the content of a table. As a rule, a table should stand alone and not require the reader to search for abbreviations or text to explain what the table is presenting.

Table 1.2 shows an example that meets these rules and presents basic data collected in an exercise physiology laboratory. This tabular format can be modified to fit many data sets.

Table 1.2 Sample Laboratory Table

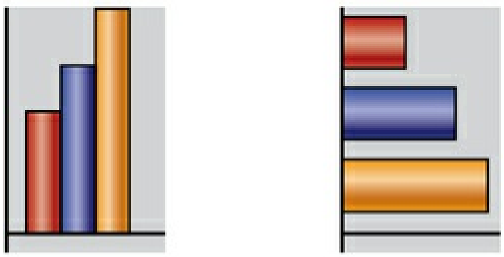
Characteristics	Mean	SD
Age (y)	22.2	±1.0
Height (m)	1.72	±0.02
Weight (kg)	83.5	±5.6
Percent body fat (%)	8.2	±3.1
$\dot{V}O_2max$ (ml · kg^{-1} · min^{-1})	45.2	±2.2
1RM back squat (kg)	110.2	±10.5
1RM bench press (kg)	85.4	±4.6

1RM = 1-repetition max; SD = standard deviation.

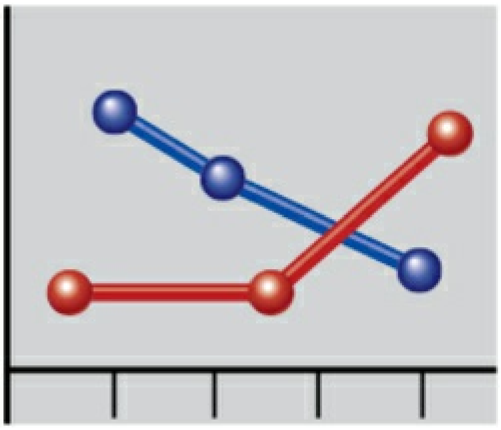
Another way to present data is by using a figure. Deciding whether to place data in table or figure form depends largely on whether a picture of the results (i.e., a figure) will work better than the actual numbers (presented in a table). If the data are better represented as a figure, consider the following rules (39):

- Make sure the figure is clearly labeled and easy to read.
- Present important information so that it is easily evaluated.
- Create a figure that is free from visual distractions.

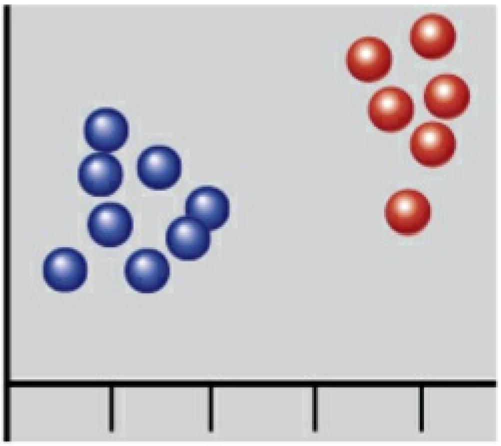
Determine what type of figure will best represent the data. Types include bar and column charts, line graphs, scatter plots, flow charts, and pie charts.



- *Bar and column charts:* These figures are useful when comparing single responses—often a mean or a single most important time point—between treatment groups. Though not the best method for determining trends over time, column charts can be used for comparing amounts over time so that trends can be seen or for comparing variables between groups. You can often use shading or coloring to distinguish between columns and thus help your audience easily interpret the data. You can also depict standard deviations and standard errors of the mean in order to make the chart more descriptive.



- *Line graphs:* This type of graphical representation is often used to present longitudinal data and show how things change over time. When creating charts of this type, time is often placed on the *x*-axis and the variable being measured or quantified on the *y*-axis. When multiple lines are placed on these charts, it is prudent to use shading, differing symbols, and broken or colored lines to allow the reader to easily distinguish between variables.



- *Scatter plots:* In this type of chart, each point on the plot represents a data point on the *x*-axis and the *y*-axis. As a result, it is easy to see the patterns of individual scores. Because scatter plots illustrate individual data points, researchers can use them to gain a sense of the spatial distribution of the results and to determine linearity, outliers, or clumps of data. Researchers often facilitate interpretation of the data by using multiple colors or symbol shapes to distinguish between groups.